DETERMINING MANAGERIAL METHODS OF
PRODUCTIVITY MEASUREMENT WITHIN
CIVIL ENGINEERING DESIGN UNITS

THESIS

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DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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Productivity in the United States is declining. We have slipped from the leader of the world to eighth among nations. Recognizing this, Department of Defense (DOD) leaders directed the implementation of a DOD Productivity Program. The key to any productivity program is the development of a productivity measurement system. The purpose of this ~~study~~ is to determine a managerial method for productivity measurement within a base level Civil Engineering Design Section. Current methods of productivity measurement were reviewed and found to be deficient. A relatively new method, Constrained Facet Analysis, was chosen. Design section inputs and outputs were determined. A data set was generated to a predetermined efficiency result. The Constrained Facet Analysis model was run using the generated data, and its computer output was compared to the predetermined efficiency result. The comparison showed identical results for the computer model and the predetermined efficiencies. The authors concluded that the computerized Constrained Facet Analysis model is an accurate and valid method of determining productivity within a base level Civil Engineering Design Section. The limitations of this method of productivity measurement are discussed. Further research, using data from real design sections, is recommended before implementation of the model. The model should be used as a managerial aid to improve organizational performance. It should not be used to evaluate manager's performance.

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DETERMINING MANAGERIAL METHODS
OF PRODUCTIVITY MEASUREMENT
WITHIN CIVIL ENGINEERING DESIGN UNITS

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Engineering Management

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Abstract

Productivity in the United States is declining. We have slipped from the leader of the world to eighth among nations. Recognizing this, Department of Defense (DOD) leaders directed the implementation of a DOD Productivity Program. The key to any productivity program is the development of a productivity measurement system. The purpose of this study is to determine a managerial method for productivity measurement within a base level Civil Engineering Design Section. Current methods of productivity measurement were reviewed and found to be deficient. A relatively new method, Constrained Facet Analysis, was chosen. Design section inputs and outputs were determined. A data set was generated to a predetermined efficiency result. The Constrained Facet Analysis model was run using the generated data, and its computer output was compared to the predetermined efficiency result. The comparison showed identical results for the computer model and the predetermined efficiencies. The authors concluded that the computerized Constrained Facet Analysis model is an accurate and valid method of determining productivity within a base level Civil Engineering Design Section. The limitations of this method of productivity measurement are discussed. Further research, using data from real design sections, is recommended before implementation of the model. The model should be used as a managerial aid to improve organizational performance. It should not be used to evaluate manager's performance.

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I. Introduction

Background

The last few years have brought the issue of productivity in American economy to the point that it is a national concern (3:1). United States after World War II was the leader in the economic wo and first in productivity. That trend, however, has reversed productivity is now in a downward trend. At present, the United Sta is eighth in productivity among nations (12). American industry is longer concerned about increased productivity or creating innovat ways to manufacture products more efficiently and less expensivel This is the cause for the decline in the American economy over the l decade. Nine countries now have a greater Gross National Product capita than does the United States (34). For many years, the Uni States was consistently number one. General Alton Slay recognized problem that was facing the United States when he said,

> My conviction is now very strong that we do indeed have a national problem....a national industrial productivity disease which must be addressed if we are to maintain our status as t focus of the free world's industrial, economic, and military strength. [16:2]

The American economy is not the leader it once was fifteen ye ago. This decline in productivity has had a significant impact on

Air Force and its operations. General Louis L. Wilson, Jr., summed up this impact when he stated,

> The Air Force is facing one of the most austere times in its history. In spite of increased defense budgets, our buying power has eroded with the net result that we have to do more with less. To meet this challenge, we need to fully utilize our most costly and important resource...people...by instilling in them a sense of urgency about their important role in the conduct of the Nation's critical enterprise...national security...and in doing so we must increase their productivity. [3:3]

The key to turning the declining American economy around is to increase productivity in America (34). The importance of productivity improvement can not be overstated. Without a productivity increase, the United States' standard of living will decline (16:7). General James P. Mullins, in an address to the students and faculty at the Air Force Institute of Technology, concluded, "We can not afford not to be productive; we can no longer let productivity wane (28)." Rising costs have squeezed the public's resources between public demands for service and the cost of supplying those services. There is growing resistance on the part of the public to pay for these services through higher taxes. This creates a problem. The answer to this problem is to improve productivity of the public service (18:9). Major General Robert C. Thompson, former director of USAF Civil Engineering, stated that a look into the future indicates that the Civil Engineer must do more with less through increased productivity (3:4). The key to the future of America was summed up by Thomas Edison when he said, " There is a way to do it better...find it (12)."

On October 23, 1978, a memo from President Carter was sent to the head of all Federal departments and agencies. The memo announced the establishment of the National Productivity Council. The council is to be the focal point for productivity improvement efforts in the United States (36:1). President Carter wrote the following in the memo:

> I have established this council in recognition of the vital role productivity plays in the nation's economy by helping control inflation, making the U.S. goods more competitive in world markets, and increasing the real income of the American worker..improved productivity is vital to the social and economic well-being of our nation. The Federal Government can make a major contribution to improving productivity. I expect all agencies to cooperated and assist the council in meeting its responsibilites so we realize maximum benefit from the Federal effort to improve productivity growth. [36:1]

This memo was followed in 1981 by the Government Cost Reduction Act (16:19). This act was an attempt by the federal government at productivity enhancement.

The Secretary of Defense, realizing the need for productivity, made increased productivity one of the highest priorities of the Department of Defense (18:3) The Department of Defense (DOD), the largest and most costly of all public organizations, issued directive 5010.31 that requires each military department to estalish a productivity improvement program (36:1). This directive was followed by DOD Instruction 5010.34. Howell and Van Sickle, in a master's thesis, explained the meaning of the Productivity Program:

> DoD Directive 5010.31 establishes the policy of focusing management attention on the achievement of maximum defense output within available resource levels by ... seeking and exploiting opportunities for improved methods of operations in consonance with the defense preparedness mission. The directive further states that, productivity measurement, enhancement and evaluation will be an integral element of resource management...The Directive prescribes a labor-oriented mode, but allows for total product or unit cost measures if available. [18:6]

In response to the White House and the DOD, the Air Force created a comprehensive productivity improvement plan. This plan directed all major command agencies to develop individual productivity plans, to appoint "productivity principals" as points of contact for productivity matters, and to report all productivity accomplishements annually to Air Force headquarters (37:1). In issuing the plan, General James A. Hill, Vice Chief of Staff, said:

> Productivity has received increased emphasis at all levels of government, and had consistently surfaced a key factor during congressional debates on Military Appropriations. If we are to continue obtaining the necessary funding for vital Air Force Programs everyone at all organizational levels must actively seek more productive means of accomplishing their jobs. We therefore urge your full support for this plan. [36:1]

Air Force Civil Engineering has long felt that productivity improvement was important.. The Base Civil Engineering organization is generally the largest service organization on base and usually spends 40 to 60 percent of the total operations and maintenance budget of the base (10:1). Any improvements within Civil Engineering would have a significant impact on the Air Force and DOD in general. The inefficient use of resources by USAF Base Civil Engineering organizations has a substantial impact on the overall DOD productivity level (3:3). Brigadier General Archie S. Mayes, former Deputy Chief of Staff for Civil Engineering, Strategic Air Command, presented a plan involving six points designed to improve productivity of the work force and overall efficiency of Base Civil Engineering operations (3:4). Major General Guy H. Goddard, also a former Director of Civil Engineering, stressed that the key to productivity within Air Force Civil Engineering was at the base level (3:4).

The Air Force Civil Engineering community, in an effort to increase productivity instituted an automated management information system called the Base Engineer Automated Management System (BEAMS) and a Management Review Program (MRP). This system included a list of objectives to be used as aids to increasing efficiency (2:1-2). The programs are intended to help manage the civil engineering organization more efficiently. Presently, the civil engineering organizations rely on information provided by the BEAMS system to monitor performance. The system has been found to have numerous shortcomings. In a move to increase productivity, the civil engineering community is attempting to implement a new automated management information system called Work Information Management System (WIMS). Major General Clifton D. Wright, current Director of Engineering and Services, feels so strongly about productivity that increasing productivity is one of his six strategic goals. Changes to AFR 85-1, the Civil Engineering Resources and Work Force Management Regulation, have come about as management efforts aimed at reducing impediments to productivity within civil engineering organizations (3:5).

Programs have been implemented on a national, Air Force, and Civil Engineering level all designed toward increasing productivity. By increasing productivity, we can stop rising costs that are squeezing the public's resources. This turn can only be achieved if all levels of industry and public service are involved.

Justification For Study

With the problem of declining productivity, the manager of today is faced with the problem of what to do. The major problem is that a manager can not improve productivity if he does not know his present productivity. The development of meaningful productivity measures will ultimately lead to better management in the areas of present and future operations (20:13). One way of enhancing and improving effective management is the development and use of productivity measures (20:3). A manager is given a certain amount of input, or resources which he uses to produce output. After these outputs are produced, performance feedback information and measurement is needed to indicate how well he utilized his resources to produce the output (32:2).

John Mee broke the management process down into seven sub-processes (15:2). Mee's sixth sub-process deals with productivity measurement. Not only are measurements of productivity beneficial to managers but they are a portion of managerial responsibility. Through the use of Productivity Measurement, managers can be helped in the following areas:

1. Current Operations
   a. To objectively identify efficient management
   b. To identify and take effective timely remedial action in potential trouble areas
   c. To compare the relative production efficiency of similar functions performed in different major commands, and
   d. To improve productivity and the methods and standards of operation.

2. Aid in Future Planning
   a. To improve the planned allocation of resources

b. To improve the evaluation of effects of policy constraints by:
   1) Evaluating feasibility
   2) Making more effective adjustment to comply with externally imposed constraints
   3) Measuring advantages/disadvantages (costs) of externally imposed constraints
c. To improve the integration of present policies with contingency and mobilization requirements. [26:24]

Kaneda and Wallett, in a thesis on productivity, concluded that productivity measurements are powerful tools for any manager. But these tools are more difficult to develop within military organizations because of substantive goals and policy constraints. However, some type of productivity measurement is essential to assist management (20:13). This is contrary to the military belief that rank automatically makes an Air Force Officer an instant leader and a superior manager (16:32). In public service and government organizations, regular feedback to managers is slower and less specific. This makes it all the more important that we have the information available to make good productivity choices (18:40). The following conclusion came out in a study for the Navy done by Litton System, Inc.:

> Accurate productivity measurements are powerful tools for any military or civilian manager; however, these tools are more difficult to develop within the military context for there is no profit-and-loss statement; also, a wide variety of policy constraints make an overall profit-and-loss type of productivity measurement difficult. Some type of productivty measure, however, is essential to assist management. [26:2-1]

With the current Department of Defense productivity programs, the obvious question that arises is, "How will agencies within the Defense Department know if they are or are not improving productivity?" The answer is, of course, they will not without the initiation of some measurement system (18:3). The development of meaningful productivity measurement systems is the key issue in the Defense Department productivity programs. Without the measures, the agencies of DOD have no hope of defining the present level of productivity, nor can any estimates of improvement or regression be made. With no measurements, the success or failure of new management productivity improvement efforts cannot be assessed (18:7). Combine productivity measurement with some old-fashioned belt-tightening, and significant savings in defense programs can be acheived (18:4).

The Base Civil Engineering Squadron never seems to have sufficient resources to accomplish everything called for in the mission statement (10:4). This limitation makes productivty measurement within Civil Engineering a neccessity. Lieutenant Colonel Norwood J. King, in his article "How to Increase Work Force Productivity," stressed the importance of being able to understand, measure, and increase productivity in USAF Civil Engineering (21:8). The importance to a Civil Engineering manager was summed up in a thesis completed by Baumgartel and Johnson:

> Base level civil engineering managers must be able to assess an increase or decrease in productivity in order to identify the degree of attainment of this directorate goal. Therefore, a method of measuring the productivity of a base level civil engineering organization is definitely needed. [3:21]

Given, then, the importance of productivity measurement to managers, the development of a productivity measurement model would be of significant value to the Department of Defense and the Air Force productivity programs.

Problem Statement

In the private sector, a productivity measurement system has been developed based on profit and economic standing in the market. However, federal organizations do not produce for profit, nor do they compete in the private sector markets. A new or different method is needed as it is not feasible to measure federal productivity in the same manner as the private sector (18:3). If a simple ratio of work output to input could be established, the problem would be solved. Unfortunately, that ratio is hard to apply in service organizations, and the simplicity soon disappears. The mission of the Base Civil Engineering Squadron is, "...to acquire, construct, maintain, and operate real property facilities, and provide related management, engineering, and other support work and services (10:1)." In other words, the mission is service. Simon, in his book, Administrative Behavior: A Study of Decision-Making Processes in Administrative Organizations, wrote that for public service organizations, the efficiency is measured by a statement of objectives for that activity (33:175). In service organizations, objectives are stated social or appropriate substantive results (20:1). In government, this means managers must attempt to substitute the profit measures with intangible goals such as "national defense (20:1)." A study by H.G. Rainey, comparing government organizations to private industry, showed the following differences in government organizations:

1. Greater multiplicity and diversity of objectives
2. Greater vagueness and intangibility of objectives
3. Greater tendency of goals to be conflicting
4. Greater caution and rigidity, less innovativeness [30:233-244]

These differences make the objectives hard to define and even harder to measure.

The correct selection of objectives and appropriate criteria is a critical step in trying to determine productivity. The accuracy and the meaningfulness of any productivity measure depends on the accuracy of the measurement of the respective inputs and outputs and on the appropriateness of the measurement units (26:3-2).

The main problem is determining the proper input and output measures for productivity. Inputs are usually more easily determined than outputs in service organizations. The measures of performance and productivity must be consistent and meaningful if they are to be any benefit to managers. Productivity should not be measured just for the sake of measuring (16:31). Only if the productivity measure is used by managers to improve the organization is the effort worthwhile.

Not all people feel productivity should be measured. Major Donald Fowler, in a report on white collar productivity measurement, felt that productivity in government offices should not be measured. Rather, he said productivity should be "assessed" at the macro level (16:31). While not widely accepted, Major Fowler's assessment idea does not seem so far-fetched since performance measurement techniques in use in AF Civil Engineering are almost entirely subjective (10:iii). This is because, presently, there is no acceptable objective measurement technique. The Engineering Design Section of Civil Engineering offers some special problems. The section is dominated by professionals, and professionals tend to resent having their productivity measured (9:21). It is difficult to evaluate efficiency and effectiveness of an organization whose work deals with such factors as design safety and economy (9:21).

It is obvious that some organizations are more effective than others. The problem is how to measure this against different groups or the same group, taken at different times (24:1). Accurate productivity measurements are powerful tools for all managers. The military and service context of Base Level Air Force Civil Engineering makes productivity measurement difficult. The problem is compounded by the unique nature of the engineering section within civil engineering. Presently, there is no productivity measurement method in use within the Air Force Civil Engineering Design Section. Therein lies the problem encountered by this thesis, to develop a managerial measurement method for productivity in Base Level Civil Engineering Design Section.

Research Objectives

The objectives of this research are to: 1) determine Air Force Civil Engineering Design Section outputs and inputs for productivity measures, 2) determine an appropriate objective productivity measurement technique, and 3) develop a productivity measurement model for a Base Level USAF Civil Engineering Design Section. The specific model and actual measurement of productivity for every study on productivity varies according to the study desired, the measurement approach taken, and the type of organization being studied (3:14-15). All studies, like this one, have in common an attempt to improve organizational productivity through measurement. There has been considerable research by various U.S. Air Force agencies on productivity, including:

1) The Air Force Academy Behavioral Science and Leadership Department's motivation studies.
2) The Air Force Institute of Technology.
3) The Air Force Military Personnel Center's development of officer evaluation reports.
4) The Air Force Directorate of Personnel Plan's Human Resources Development laboratories.
5) The Leadership Management Development Center's (LMDC) problem solving support.
6) The Logistics Management Center's (LMC) efforts to improve Air Force policies. [19:1]

The area of productivity and its relationships are constantly changing and growing. The efforts of this research will help future researchers and managers better understand productivity and its relationships. If a model is developed, it will help the design responsibility center/cost center fully accomplish the objectives of the Resources Management System (RMS), by enabling the manager to equate resources consumed to output realized (15:1).

Research Questions

In order to develop a meaningful measure of productivity for the Base Civil Engineering Design Section, the following research questions must be answered:

1) What are inputs and outputs for a base level USAF Civil Engineering Design Section?

2) What is the appropriate productivity measurement technique?

3) Can a model of productivity be developed using appropriate inputs and outputs?

Scope and Limitations

This research effort is focusing on the design section of Air Force Civil Engineering in the development of a productivity measurement model. If the model or its development method can be applied to other responsibility centers/cost centers within or outside of civil engineering, so much the better. The goal of this research however, is not to develop a universal model but one that is tailored and specifically able to meet the unique requirements of the design section.

A measurement model is only as good as the measurement of its inputs and outputs (26:3-2). Also, all measurement is subjective to a certain degree (10:iii). It is not the desire to arrive at a perfect or ideal measurement model. If such a model were possible to develop, it would be prohibitively expensive to run. The achievement of such a model could mean many managers would be replaced by computers (26:3-1). The desirability of this occurance is questionable.

Assumptions

We will assume that the organizational goals or objectives for the Civil Engineering Design Section have not changed significantly since Baumgartel and Johnson identified them as the following:

1. Facility Life Cycle Cost
    A. Identify and program Military Construction Projects (MCP) projects, and monitor approval, design and construction phases to ensure maximum durability and maintainability of accepted facilities.
    B. Ensure in-house design complies with AFM 88-15 and applicable building codes.

2. Facility Function
   A. Ensure new construction projects are identified, programmed and designed in a timely manner, and are designed and located in accordance with the user's requirements.
   B. Identify, program, and design contract corrections to facilities which are functionally inadequate for mission requirements.

3. Facility Protection
   A. Ensure corrective contract actions for identified facility, fire, safety, and security deficiencies are programmed, designed, and completed in a timely manner.
   B. Ensure new contract work complies with regional requirements for structural protection against weather and earthquake -related forces.

4. Facility Occupant/User Requirements
   A. Complete architectural studies of facilities to identify inadequate aesthetic conditions and facility deficiencies contributing to occupant discomfort.
   B. Ensure designed projects comply with applicable life safety and public health code requirements.
   C. Ensure identified facility life safety and health code deficiencies requiring contract corrective actions are programmed, designed, and completed in a timely manner.
   D. Identify, program, and specify custodial contracts required for base facilities and ensure contractor compliance with the contractual requirements.

5. Other Non-Facility Requirements
   A. Provide professional architectural and engineering assistance to operations branch and to other organizations as required. [3:82-83]

These objectives will be used as the organizations goals in this research effort.

Definitions

The definitions and terminology used in the field of productivity vary according to the author. To eliminate any conflicts or confusion that may arise, the following definitions will be used for this research effort. These definitions are a compilation of those currently in use in productivity literature (3;35) and are compatible with those definitions used by Kaneda and Wallett (20), whose research helped form the basis of this study.

INPUT -- the quantity of resources used by an organization during a specified period of time. Inputs can include personnel, facilities, energy, dollars, raw materials, supplies, and information.

OUTPUT -- the quantity of goods, products, and services produced or provided during a specified period of time.

EFFICIENCY -- the ratio of output to input; implies minimizing resource comsumption or maximizing output for given resources. This term does not imply the appropriateness of the output to goal attainment.

OBJECTIVES -- the desired future conditions that are subgoals of organizational goals which an organization or section wants to achieve through its activities.

GOALS -- the organizational goals that relate the activities of an organization to its environment.

SURROGATE MEASURES -- measures that do not directly measure an aspect of efficiency, effectiveness, or productivity, but research has shown are indicators of actual performance.

PRODUCTIVITY -- efficiency of an organization in a goal related direction. Given that an organization is meeting its mission, productivity can be measured as a ratio of output to input.

Summary

Productivity in the United States is declining. We have slipped from the leader of the world to eighth among nations. The decline will continue unless we do something about it. The economy of the United States and our standard of living will drop without an increase in productivity. Recognizing this, DOD leaders have directed the implementation of a DOD Productivity Program. The key to any productivity program is the development of a productivity measurement system. How will we know when the highest level of performance has been reached with the least expenditure of resources? Obviously, a measurement technique is needed.

Productivity measures can be a powerful tool for managers in a military organization. However, outputs for a service-oriented, military organization such as civil engineering are vague or difficult to define. It is obvious some organizations are more productive than others. The key is developing a productivity measurement model with which to evaluate an organization's productivity. Presently, there is no productivity measurement model for the design section of Air Force Civil Engineering.

Productivity will ultimately lead to better management in current and future operations. However, before this can be realized an appropriate productivity measurement model must be developed.

II. Review of the Literature

A review of the literature concerning productivity revealed a plethora of views on productivity. Each article has a slightly different definition of productivity. Rather than review and comment on the extensive amount of literature concerning productivity in general, the authors chose to limit this presentation to those works thought to be most applicable to this research effort. That decision was based on two factors: 1) An exhaustive review of productivity in general would not contribute substantially to this report, and 2) Such exhaustive reviews have been accomplished by others (we recommend the technical report by Tuttle (35)). Therefore, this literature review will concentrate on the five articles the authors felt were most relevant to the task at hand.

DOD Productivity Program

The DOD established this program in 1975, with the instruction that each DOD Component implement a Department/Agency-wide Productivity Program (required by DOD Directive 5010.31) (13). The objective of the program is to obtain maximum productivity growth (i.e. increase goods produced or services rendered relative to the resources used) to help offset personnel cuts, reduce costs, and free funds for other requirements.

DOD first defined productivity as a combination of efficiency and effectiveness, saying that organizations must be efficient (accomplish the right things at the lowest expense) and effective (accomplish the right things at the right times). Thus, "The efficiency with which organizations utilize all types of fund resources to accomplish their mission represents total resource productivity (13:1)." Later in the same instruction documents, DOD states that a productivity index is "the percentage ratio of goods produced or services rendered (outputs) to resources expended (inputs) during a current period in relation to a base period (13:11)." This second definition of productivity is the same as our definition of efficiency; thus, the official DOD definition of productivity is unclear.

The instruction goes on to list the minimum department functions that must provide productivity indicator data. The instruction also suggests possible indicators for each department function. The Air Force Civil Engineering Design Section is not specified in the instruction (13:Encl 3:4-8).

Hanley and Smith

A 1976 AFIT thesis by the research team of Hanley and Smith analyzed the effect of labor manhour requirement estimates on the measurement of Air Force Civil Engineering (AFCE) productivity (17:7). Their findings indicated that significant variation existed in the standard manhour requirements estimates being computed by Air Force planners for any given project (17:58). Those estimates were the standards against which actual labor manhours were compared to compute a productivity index. Since the existence of variation would result in different standard estimates for the same project at different bases, Hanley and Smith concluded that, "Comparisons of standard estimates with actual labor manhour expenditures result in unreliable productivity ratios (17:73)."

Baumgartel and Johnson

In 1979, the AFIT research team of Baumgartel and Johnson attempted to develop productivity measures for a USAF base level civil engineering organization (3). They defined productivity as "the measure of effective and efficient use of resources to attain results which are directed towards the strategic level organizational goals, through the branch level objectives (3:24)." In their model, they proposed to measure productivity by taking the average value of the performance indicators for each branch objective, divided by the total resources used to attain the level of output (3:24). The resulting ratio of performance achieved to resources consumed represented that branch's effort to support a specific objective during that specified time period; a series of measurements taken over time would be an indicator of any change in the branch's productivity (3:71-72).

It should be noted that their measurements would require a length of time before any interpretation of the ratio would be possible. Additionally, each organization would be measured against itself; no mention is made of the ability to compare one organization to another based on the ratios.

Baumgartel and Johnson concluded that while the input data was available in great quantity and detail, the output data needed for their index calculations was limited. Using their defined objectives, they found it difficult to classify the output information. They could not measure readiness or response output, and they questioned the inclusion of any training or exercise evaluation results (3:108).

Tuttle

In Thomas Tuttle's extensive review of productivity implications for the Air Force, he offers five different definitions of productivity, three of which bear mention. The economist defines productivity as the ratio of output to input when both output and input are measured in real (physical volume) terms (35:7). The engineer, on the other hand, defines productivity from the idea of mechanical efficiency (35:8):

$$\text{Productivity (efficiency)} = \frac{\text{Useful Work}}{\text{Energy}}$$

or

$$\text{stated another way: Productivity} = \frac{\text{Useful Output}}{\text{Input}}$$

In comparing the engineer's definition of productivity to the economist's, three important distinctions should be made. First, the upper limit of efficiency for the engineering definition is unity (one), while in the financial definition, the ratio can and should exceed 1. Second, the engineering definition distinguishes between "total" output and "useful" output (i.e. goal directed, quality output) (35:9). Finally, the purpose of the engineering definiton is to measure individual or small unit operations, while the economist's approach is to develop statistics for comparing total industries (35:9).

The manager appears to have a broader interpretation of productivity. Based on a nationwide survey of Chief Executive Officers (CEO) and Industrial Relations Officers on their definitions of productivity, "Virtually 9 out of 10 managers would include quality, effectiveness and efficiency in their definition; 7 out of 10 would add the idea of work stoppages, waste, shrinkage, sabotage, absenteeism and turnover; and 6 out of 10 managers would include measures of customer or client satisfaction (35:11)." From that, one can conclude that there is a wide difference of opinion as to the manager's definition of productivity.

Tuttle concludes that an Air Force organization's definition of productivity should incorporate the concepts of both efficiency and effectiveness. Also, any productivity measurement scheme for an organization should include multiple measures of both efficiency and effectiveness (35:76). Finally, Tuttle identifies seven desireable characteristics of a set of productivity measures:

1. Completeness - the set of measures adequately covers the significant facets of the organization's mission.

2. Comparability - the measures should be applicable over time to permit longitudinal measurements of productivity within the organization.

3. Input coverage - outputs used in measurement represent all the relevant inputs.

4. Compatibility with existing data sources - attempt to use data already available.

5. Cost effectiveness - the benefits derived should exceed the costs incurred in making the measurements.

6. Consistent across organizations - the most useful measures would be relatively invariate across organizations performing the same function.

7. Acceptable to organization members - the managers and workers being measured accept and support the measures. [35:77-78]

Kaneda and Wallett

In 1980, the AFIT research team of Kaneda and Wallett set out to develop productivity measures for the design section of a base civil engineering organization. Using a questionnaire survey instrument, they collected data on proposed productivity measures from base civil engineers, chiefs of design, and chiefs of industrial engineering throughout the United States. Statistical analyses then yielded six measurements acceptable to the majority of survey respondents. The six productivity measures are:

1. Total estimated dollar amount of contract projects and in-house work orders designed divided by total design manhours.

2. Total number of projects designed (complete and ready for acquisition action) divided by total design manhours.

3. Total number of facility inspections and utility systems surveys completed divided by total manhours to complete surveys and inspections.

4. Total estimated dollar amount of architect-engineer (A-E) design acquisition packages prepared divided by total manhours to prepare.

5. Total estimated dollar amount of contract projects and in-house work orders designed divided by total design labor cost.

6. Total number of projects designed (complete and ready for acquisition action) divided by total design labor cost. [20:76]

Two additional measures were identi[illegible] by two prominent partial samples (the Base Civil Engineers and t[illegible]agers with over 10 years experience in a base civil engineering organization), and may be considered useful to the managers of the design section:

1. Total contract funds obligated (i.e. Military Construction Program and Operations and Maintenance) divided by total design manhours associated with the contract funds obligated.

2. Number of work orders reviewed and/or evaluated divided by total manhours required for review and or evaluation. [20:77]

Kaneda and Wallett concluded that those productivity measurements should be useful as a starting point to measure productivity trends. They also stated, though, that every measurement may not be applicable to every design organization, and advised against comparing dissimilar design sections (i.e. design sections with dissimilar projects, level of engineer experience, etc. (20:79-80).

Summary

The preceding literature review has been a chronological review of productivity in general, and a narrowing of the scope of productivity measurements from DOD to Air Force to base level Civil Engineering to the Civil Engineering Design Section. Hanley and Smith showed that productivity should not be measured as a ratio of actual manhours to standard manhours required, as the estimates for standard manhours required were too varied. Baumgartel and Johnson then proposed a model for measuring productivity of a total base level Civil Engineering organization by using performance indicators for branch objectives, divided by total resources used to attain those objectives. Baumgartel and Johnson could not classify their outputs by inputs consumed, though. Kaneda and Wallett then looked at a portion of a Civil Engineering organization--the design section--and identified at least six productivity measures that would be useful to managers of design sections in determining the section's productivity.

III. Methodology

Given that productivity measurement is important and necessary, we now will attempt to provide a means for measuring productivity in a Civil Engineering Design Section. The desired end result will be some form of a productivity model that will permit the design chief to analyze his section and then make managerial decisions that will improve the performance of his section based on that analysis.

Four steps must be taken to obtain the desired result of a productivity measurement for a design section. First, we must determine what the actual inputs and outputs of a design section are. That is, we must know all of the resources that a design section receives, and we must know what products, services, and activities result from the consumption of those resources. Second, we must have some method for measuring those inputs and outputs. The inputs and outputs themselves can be measured, or they can be measured indirectly by using a surrogate. Third, the input and output measures must be gathered. Finally, some form of mathematical analysis of the data must be performed to determine the unit's productivity rating or measurement, either with respect to other design units or with respect to the unit itself over a period of time.

Overview

A review of the various resources (inputs) and products and services (outputs) of a design section yielded a list of over thirty factors to be considered in the measurement of a design section's productivity. The list was then analyzed and subsequently reduced to a total of twenty-six inputs and outputs representing the work of a design section. Simultaneously, various analytical techniques were examined for use in analysis of the input and output data. One technique, Constrained Facet Analysis (CFA), appeared to be exactly the type of model needed to analyze a complex organization with multiple inputs and outputs. Accordingly, it was selected as the analysis technique.

Due to the selection of the CFA model and its short history, the authors felt that a demonstration of the model was appropriate. Data was gen^rated for fifty-two organizations. The data was constructed so that four organizations were definitely efficient with respect to the other organizations, and four units were definitely the least efficient. A successful demonstration of the model would occur if the CFA technique verified the four efficient organizations and the four most inefficient organizations.

Analysis Techniques

First of all, it must be recognized that the problem being confronted is one of multiple inputs and multiple outputs. That is, a design section does not simply take manhours and turn them directly into design drawings. Other inputs (eg., number of personnel, supplies) and outputs (eg., site inspections, design reviews, etc) are involved. Therefore, any analysis technique must be capable of handling both multiple inputs and multiple outputs simultaneously, permitting interdependence of factors to be included as part of the examination.

The next step is to research those techniques currently in use or thought to be applicable to the problem at hand. Three different techniques were found to be available. The three analysis techniques chosen were those felt by the authors to be the most appropriate for this problem, though certainly not exclusive of all others. The techniques examined were: 1) ratio analysis; 2) regression analysis; and 3) Data Envelopment Analysis (DEA).

Upon examination, the Constrained Facet Analysis (CFA) technique--an adaptation of DEA--was selected as the appropriate method. The three techniques will be examined in the following section to present the reasons why CFA was chosen over the other methods. Each method will be explained along with its relative strengths and weaknesses as revealed by the research.

<u>Ratio Analysis</u>. Ratio analysis is a one-to-one comparison of outputs to inputs used frequently today as measures of productivity or efficiency. Ratio analysis is popular because it is easy to use and familiar to managers (18). Managers are comfortable with a measurement that conveys some tangibility (eg., number of widgets produced per hour). It can be used without knowing the production process or when the production process is difficult to model (5:23).

The problem with ratio analysis lies in its inability to consider the full range of inputs and outputs and their interactions simultaneously (5:23). Ratios typically consider one input and one output at a time. Thus, any one ratio is only a partial measurement at best of an organization's activity (18). A number of ratios are needed to completely cover the range of the organizational activity, and yet they still do not portray any of the interactions between outputs competing for the same resources or inputs dependent on one another.

Comparisons between organizations are difficult when using the ratio method, particularly when one organization ranks higher in some measurements while the other organization ranks higher in other measurements. The ratios must then be given some order of importance to permit comparison between the organizations. As the number of ratios grows (ie., the number of inputs and outputs to be compared increases), the task of weighting and assimilation grows multiplicatively (5:23).

Regression Analysis. Regression analysis attempts to find a relationship between some response variable (productivity) and some set of secondary variables (productivity indicators). The objective is to find a linear equation for the relationship so that the secondary variables can be used to better predict or estimate the response variable (productivity) (25:523).

Least squares regression is defined as that curve (line) which minimizes the sum of squares of the lengths of vertical line segments drawn from the observed data points on the scatter diagram to the fitted curve (22:45). It is important to note that a least squares regression of a single output, multiple input case having both positive and negative error terms will produce a curve (line) of average relationship (5:18). The curves are not frontier or extremal relationships, as actual outputs can lie above or below the curve.

In the multiple output case, regression analysis must be performed on each output separately. As in the ratio analysis, this prevents consideration of the impact of interdependencies or competition for resources among the variables. In their paper "Managerial Efficiency

Measurement, Theory and Applications," Bessent, Bessent, and Cla
explain the impact of this deficiency as follows:

> Each regression equation might be able to predict adequately an expected level of a single output for an organization, assuming this organization could experience an of the random fluctuations or inefficiencies of the industry (all firms) and recognizing that the influence of other outputs are implicitly taken into account by the deviations from the regression line (residuals). But these equations cannot predict the expected output of an organization whose variations and/or inefficiencies are significantly affected by the given technology and policies of the firm which are not random. Magnitudes of actual outputs of an organization are influenced by both local and corporate policy which may prevent the true expected output values of the orgnization from conforming to the corresponding regression estimates. [5:19]

If it is accepted that a linear regression model is appropriat then the regression estimates must reflect an efficient input/outp relationship (5:20). Therefore, the rate of technical substitution is assumed to be constant and the rate at which an input is converted into an output is the same for all of the organizations in the model (5:20. That means that an organization cannot decrease one input without increasing another input, or total output must decrease. Also, an organization cannot increase output without some increase in inputs. While those statements are true of the efficient organization, inefficient organizations should be able to increase output without increasing inputs or decrease inputs while holding output constant to increase efficiency.

Data Envelopment Analysis (DEA). Data Envelopment Analysis is a relatively new method of evaluating productivity in not-for-prof organizations. After researching the other available analysis method, we concluded that DEA offered the best possibility of being able measure productivity in a Civil Engineering Design Section. A memb of the AFIT faculty, Lt Col Charles T. Clark, has been very active in pioneer work with the DEA model as part of his Doctoral effort, and has been of great assistance to this research team in explaining the procedures and results of DEA. His assistance was particularly valuable because of the extremely small body of literature available on DEA. Therefore, the following discussion of DEA and its offspring, Constrained Facet Analysis (CFA), is drawn from class lectures from Lt Col Clark and two papers which he contributed to.

Data Envelopment Analysis is a fractional programming model for measuring the efficiency of similar management units (5:1). The model is capable of taking into account both multiple inputs and multiple outputs; it then calculates an efficiency rating for each unit relative to other similar units that have produced greater outputs with their inputs.

The approach to DEA was conceptualized by M. J. Farrell in 1957, in a paper entitled, "The Measurement of Productive Efficiency (8:3)." His work provided a major breakthrough in specifying a frontier of relative efficiency while not assuming any particular form for the industry production function (5:4). Subsequently, work done in 1978 by Charnes, Cooper, and Rhodes solved some mathematical computational problems in Farrell's work, and it was their operational linear programming model which they named "Data Envelopment Analysis (8:3)." Computer software for solution of the model was provided by the team of Ali, Bessent, Bessent, and Kennington, and field applications began in 1980 (8:3).

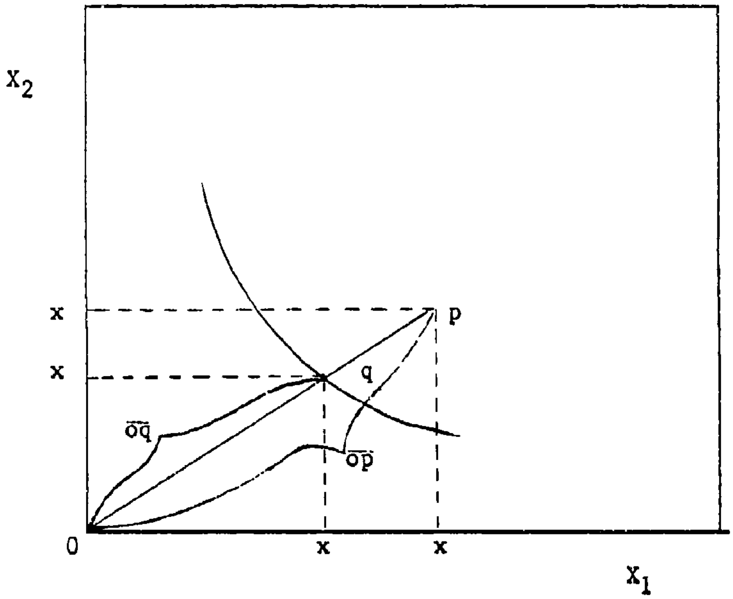

Figure 1. Farrell's Efficiency Isoquant

Figure 1 represents Farrell's concept of an efficiency frontier--an isoquant along which various combinations of inputs x_1 and x_2 are all equally efficient in producing one unit of output. Again, this isoquant is established with observed units operating at maximum relative efficiency. Any inefficient unit must use more of one or both of the inputs. Therefore, no observations can fall between the isoquant and the origin. Inefficient units will appear somewhere above the isoquant, as illustrated by point p. Efficient units appear on the isoquant, as represented by point q. The distances from the origin to point p and q, respectively, can be represented by the line segments $\overline{op}$ and $\overline{oq}$. Farrell defined the technical efficiency of unit p as the ratio $\overline{oq}/\overline{op}$ (5:4). That is, unit p must decrease its inputs x_1 and x_2 by the ratio $\overline{oq}/\overline{op}$ to be equally efficient as unit q.

One of the most important points to be made concerning DEA is the idea that each management unit is evaluated against all other similar units ("similar" meaning having roughly equal mixes of inputs and outputs). Those determined to be most efficient are assigned a rating of 1.0 and are placed on a frontier which the inefficient units are compared to. Thus there is no artificial standard being used as a yardstick; management units are measured against the other similar management units (called a 'neighborhood") in the group with the most efficient units becoming the basis for comparison. Observed standards are used as opposed to the usual theoretical standards. Farrell, as quoted in Bessent, Bessent, and Clark, noted that, "...it is far better to compare performances with the best actually achieved than with some unattainable ideal (5:4)."

Some requirements must be met by the organizations being measured before DEA can be used. First of all, organizations must be using varying amounts of the same resources (5:14). The authors believe CE design sections meet that criterion. All design sections are composed of some mix of military and civilian personnel and receive various amounts of funding from a central authority. Every design section is responsible for the same tasks, although their actual output varies from base to base. Thus, the design sections are sufficiently similar to satisfy the first requirement. Second, it is important to select as many inputs and outputs as possible depending on how many organizations are being measured (5:14). Input and output selection is discussed later in this chapter; we will use at least twice as many organizations as the total of inputs and outputs chosen.

It is also important to observe the following rules, as outlined in Bessent, Bessent, and Clark (5):

> 1. All measures should be total quantities or ratios which have a common denominator.
>
> 2. All units must use some amount of each input to produce some amount of each output.
>
> 3. Input measures should be selected that have a positive relation to output--that is, an increase in the input should cause an increase in output.
>
> 4. Regardless of how a resource is acquired, it should be included in the analysis if it has some affect on the production of outputs.

While the Data Envelopment Analysis technique is effective in identifying efficient and inefficient organizations, it is limited in its ability to provide planning information (8:2-3). Work by Clark at the University of Texas resulted in a new method of computing efficiency called Constrained Facet Analysis (CFA), which was then sucessfully tested in field work by Bessent and Bessent (8:3). The extensions of efficiency analysis developed in CFA allow the managers to identify those organizations which had similar inputs but higher outputs (ie., those that were more efficient) (8:4). They are then rank ordered in terms of similarity and available to the manager of the less efficient organization for review. That manager can then talk to or visit the more efficient organizations to determine what it is that makes them more efficient.

Constrained Facet Analysis is a normative type model, meaning that it performs optimization calculations. As such, it is an abstract mathematical model that is very difficult to understand and validate (4). CFA has been used successfully in three areas: 1) the Texas Public School system; 2) aircraft maintenance, and 3) a mental hospital (4). Its limited use to this point is explained by its short existence.

The CFA model, as presented in the paper by Bessent, Bessent, Clark, and Elam, is shown in Appendix A (8:16-19).

Summary of Analysis Techniques. The Constrained Facet Analysis (CFA) model has been chosen over ratio analysis and regression analysis. CFA is an offspring of Data Envelopment Analysis (DEA) that improves the management information provided by DEA.

The CFA model exhibits the following desirable characteristics:

1. The model simultaneously considers multiple inputs and multiple outputs.

2. Results in aggregate measures of efficiency for each organization.

3. Units are evaluated as efficient or inefficient relative to a neighborhood frontier region of actual achievement.

4. The maximum achievable efficiency value is one (1.0).

5. The inputs and outputs do not require common scales or units of measurement

6. Indicates input overages

7. Indicates output shortages

8. The information provided is a major improvement over those models currently used (ie., ratio and regression) in the measurement of public service productivity.

Input and Output Determination

The approach in determining inputs and outputs for the Constrained Facet Analysis model is outlined in a paper by Bessent, Bessent, and Clark entitled "Specification of Inputs and Outputs (6)." As a prerequisite for the CFA model, both the necessary data and the model itself should be able to interface with the existing management information system. The data should be available from the information currently compiled or recorded in the base level Civil Engineering organization to avoid any additional administrative workload.

The current management information system in use in the Civil Engineering community is the Base Engineer Automated Management System (BEAMS). This system has been described as probably the most comprehensive performance reporting system in use in the Air Force today (20:33). BEAMS has a huge historical data base. One of the purposes of BEAMS, as outlined in Air Force Manual 171-20', is to allow more efficient and effective management of resources by the base Civil Engineering organizations (31:1).

BEAMS has an outline subsystem interface that causes the data from a single update transaction to be fed into other files that require the same information (31:2). Two of these subsystems that are important to the base level Civil Engineering Design Section are the Labor and Prime BEEF Subsystem and the Civil Engineering Contract Reporting System (CECORS). The Labor and Prime BEEF Subsystem provides for the accounting of authorized and assigned personnel, the reporting of labor expended against specific work orders, and the accounting for time other than direct labor expended against specific work orders. The Civil Engineering Contract Reporting System maintains the status of all service contracts and all active and programmed projects regardless of fund source. Additionally, CECORS produces a monthly report for submission to the responsible MAJCOM, and includes two optional engineering design backlog management capabilities (31:3-4). The importance of these subsystems will be seen when the inputs and outputs are developed. Additional data that is not maintained on these sybsystems can be obtained using an Air Force On Line Data System (AFOLDS) retrieval that allows the user to specify exactly what data he wants (31:8).

One criticism of BEAMS has been that the data is not current. Some have questioned the integrity of the data. The time lapse in data permits examination of the data prior to entry or manipulation to make the situation reflect a more favorable situation (31:9). This would not be a problem on a productivity measurement model since productivity is rarely figured on a daily basis.

The future of BEAMS is uncertain with the new proposed Work Information Management System (WIMS). However, the proposal is for WIMS to be implemented in addition to BEAMS. One thing that is certain in BEAMS'S future is that it will be aound for awhile with or without WIMS. This is important in the implementation of the productivity measurement model since the data must be available on a management information system for the model to be useful. It would be fruitless to develop a model that would be rendered obsolete by the abolition or replacement of the management information system on which the data is maintained. This does not appear to be the case with the Base Engineer Automated Management System. It will continue to be in existence in the future with or without a base level Civil Engineering Design Section productivity measurement.

The first step in the determination of inputs and outputs (the process is outlined in Figure 2) is to determine the decision making unit (DMU). The decision making unit in this research project is the base level Civil Engineering Design Section.

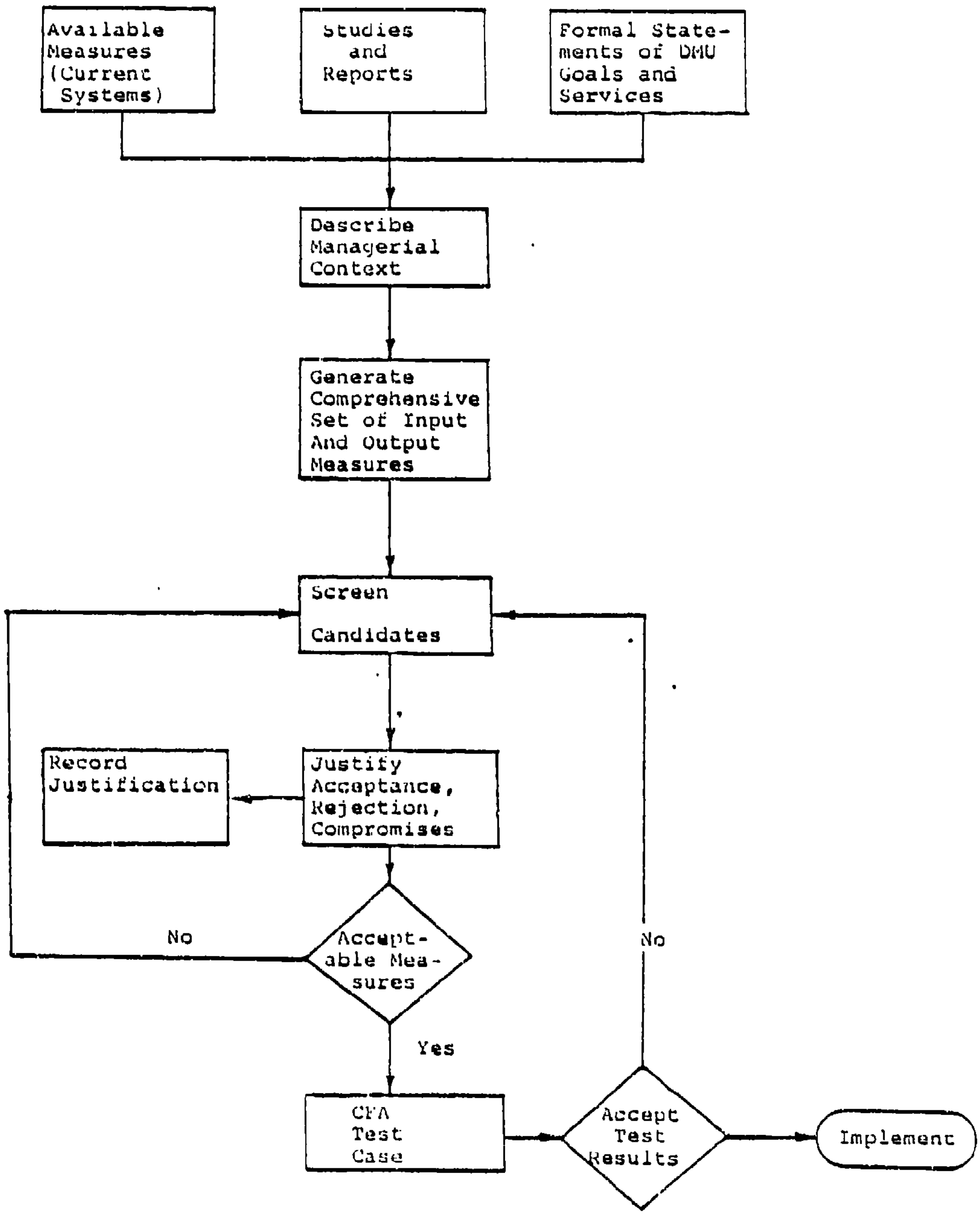

Figure 2. Input and Output Determination Diagram [6:2]

Once the decision making unit has been selected, the next step is to develop a formal statement of the DMU goals and services. These goals and services will be those organizational objectives determined by Baumgartel and Johnson (3) and stated in Chapter I.

The next step is to review all pertinent studies and reports. This review was done as part of the literature review conducted in Chapter II of this research effort. The most applicable was a research effort conducted by Kaneda and Wallett (20) in a master's thesis at the Air Force Institute of Technology, School of System and Logistics. As part of the research they developed a suggested productivity measurement system for the base level Design Section. This leads to step three which is determining available measures or current systems (6:2). The system developed by Kaneda and Wallett was never adopted by the Air Force and is not in use today.

The next step is to describe the managerial context. In developing this managerial context, the organizational goals, operational requirements, and managerial system must be evaluated (6:1). The views of key managers, analysts, and technicians should be sought while determining the managerial context (6:1). This was done in several ways by Kaneda and Wallett. The first way was using a panel of fellow Facilities Management students at the Air Force Institute of Technology (AFIT) School of System and Logistics. This panel consisted of five members with 5 to 12 years experience in the Air Force Civil Engineering career field (20:84). Each member of the panel had also been associated with or managed a base level Civil Engineering Design Section (20:84). The second way Kaneda and Wallett collected the views of experts was using a panel made up of faculty members from the Air Force Institute of Technology School of Civil Engineering (20:85). This panel of experts provided a forum for criticism and recommendations for improvement.

This method was selected for use in this research effort also. Two panels were selected and used as a sounding board to provide criticism and recommendations. The first panel consisted of AFIT Engineering Management students with at least 6 years civil engineering experience and some design experience. The second panel was comprised of AFIT School of Civil Engineering faculty. The members of the panels are shown in Appendix B.

The next step in the determination of inputs and outputs was to generate a comprehensive set of input and output measures. First we will discuss identifying relevant input measures. Kaneda and Wallett used only direct labor cost and manhours (20:54). This research effort analyzed a number of possible input measures. In generating a comprehensive list of inputs, a total of six inputs were considered. This list was submitted to the two panels for screening for relevancy and completeness. From this list, all six inputs were selected for inclusion in the model. These inputs are as follows:

1. Labor manhours
2. Labor costs
3. Years experience
4. Personnel skill level aggregate
5. Number of professional educational courses completed
6. One over the number of additional duties performed

The amount of equipment available, facilities available, and overhead were not included in the analysis. These were analyzed by Kaneda and Wallett, and they concluded that these did not vary significantly in various design sections. The reason given for this small variance is that all the design sections are controlled by the same organizational structure. Additionally, the amount of equipment, materials and overhead allocated for the exclusive use of the Civil Engineering Design Section is not maintained in the records of the Base Engineer Automated Management System. Thus, including these inputs would not be keeping with the restraint to avoid an additional administrative workload.

Output measures are difficult to develop. The Civil Engineering Design Section has different outputs every day of the year, and one design unit has different outputs from the next. Output measures must be used which enable these organizations to be compared to one another. Kaneda and Wallett came up with twenty-six possible output measures.

The twenty-six measures of Kaneda and Wallett were used as the starting point in developing the comprehensive list of outputs. The two panels were used to help revalidate the output measures developed and add to or delete other measures. They reviewed the inputs and outputs to ensure that the list was complete (ie. all resources, products, and services were represented) based on their experience. A total of thirty-three output measures were considered and analyzed. From these, twenty measures were selected for use in the model. These outputs are:

1. Total contract funds obligated

2. Estimated dollar amount of all projects designed (complete and ready for contracting action)

3. Total O&M maintenance and repair project funds obligated

4. Total O&M minor construction funds obligated

5. Total number of projects designed (complete and ready for contracting action)

6. Total number of facility inspections and utility system surveys completed

7. Total number of special technical studies and reports completed

8. One over total funds expensed on contract change orders

9. One over number of contract change orders

10. Total estimated dollar amount of in-house work orders designed

11. Total estimated dollar amount of architect-engineer packages prepared

12. Total A-E design funds obligated

13. Estimated dollar amount of MCP Project Books

14. Number of work orders reviewed and/or evaluated

15. Number of technical reviews accomplished on designed projects

16. Pages of project specifications

17. Total number of oral presentations made

18. Number of facility surveys conducted

19. Total hours or surveys completed

20. Number of pages of engineering drawings completed

The complete list of inputs and outputs analyzed, along with the reason for the rejection of some of the measures, is presented in

Appendix C. The selected inputs and outputs are also further explained in Appendix D.

Several inputs and outputs have the form of "one over" a measure. This is necessary to maintain the relationship that an increase in inputs will result in an increase in output. This is the positive relation referred to by Bessent, Bessent, and Clark (5).

Each input and output measure, while being analyzed, was evaluated against several different sets of criteria. This step was necessary due to the unique nature of the data (as explained in the following section, the data was generated by the authors). Inspection or statistical analysis of the data would not reveal faulty measurements, due to its special development. One of the sets of criteria used was developed in a thesis by Armstrong and Dougherty, A Study of the Development of Output Measures. The criteria are:

1. Based on determined mission
2. Measure permits direct evaluation
3. Measure is based on objectives
4. Causative relationship exists
5. Measure is needed
6. Measurement is not a restatement of resources
7. Data for measurement is quantifiable-programable
8. Measurement is meaningful to management
9. Data for measure is available
10. Structure agreement exists
11. Measurement is homogeneous with like measures
12. Measure is matchable to expense
13. Measure provides for continuity and compatability

14. Measure is not a composite if other alternative exists [1:98]

The final list of selected inputs and outputs were then evaluated against the seven characteristics of productivity measures recommended by Tuttle (35:77-78) and discussed in Chapter II of this research. The outputs and inputs satisfy five of the seven characteristics. The characteristics satisfied are those of completeness, comparability, input coverage, compatability with existing data sources, and consistency across organizations. The two characteristics not satisfied are cost effectiveness, and acceptable to organization members. These characteristics can not be appropriately determined until the measurement model is implemented and in use. Only at this time can the final two characteristics be determined. With five of Tuttle's seven characteristics satisfied, and Bessent, Bessent, and Clark's (5) rules for inputs and outputs complied with, the selected inputs and outputs were used for data generation.

Data Generation and Preparation for Analysis

The data used in the development of the productivity measurement model was generated by the researchers. Actual data from real Civil Engineering Design Sections was not gathered.

The decision to simulate real data is based primarily on the choice of the statistical analysis method. Recent research has produced a new method for measuring the relative efficiency of an organization with respect to other similar organizations performing similar operations with similar resources. That method is called

Constrained Facet Analysis (CFA) and is explained in detail in this chapter in the discussion of analysis methods.

The authors believe that Constrained Facet Analysis will prove to be a powerful management tool when knowledge of its existence spreads and more applications of the model are made. The authors have no reason to believe that the model cannot successfully be implemented in an Air Force Civil Engineering Design Section. However, it is recognized that CFA has not yet been applied to a civil engineering problem. Any application of the model to Civil Engineering using actual data could not be reliably shown to reflect the true state of nature, unless the true state of nature was already known. Therefore, the use of CFA in a civil engineering application, such as a design section, is needed to demonstrate its capability, but it must be applied so that the output of the model verifies a previously known state of nature. One reliable way of knowing the true state of nature is to manufacture it.

Data Generation. Identification of inputs and outputs revealed 26 candidate measures. As stated in the analysis section, data from twice as many organizations, or 52 units, will be used in the analysis.

The data will reflect the following situations:

1) Efficient large units with a concentration of in-house design work

2) Inefficient large units with a concentration of in-house design work.

3) Efficient small units with a concentration of in-house design work.

4) Inefficient small units with a concentration of in-house design work.

5) Efficient large units with design work contracted out to A-E firms.

6) Inefficient large units with design work contracted out to A-E firms.

7) Efficient small units with design work contracted out to A-E firms.

8) Inefficient small units with design work contracted out to A-E firms.

Based on the authors' experience, some typical values for each input and output were determined. Using that group of values, two ranges were developed--one for small organizations and one f(. large organizations. Within each of those two ranges, values were then adjusted to reflect either an in-house design concentration or an A-E contract design concentration. Thus, four major divisions were developed within the organizations. These divisions are 1) large units with in-house design work, 2) large units with A-E contracted design, 3) small units with in-house design work, 4) small units with A-E contracted design. One organization in each division was chosen to be the efficient organization and one organization selected to be the least efficient organization. The most efficient organization was then assigned the lowest input values within its division and the highest output values for that division. The organization selected to be least efficient was given the highest inputs and the lowest output values for its division. By maintaining the values of inputs and outputs within the prescribed divisions, it was hoped that the particular "neighborhood" of organizations could be fixed. The data was generated for the following conditions to exist:

1) Organization 1, the efficient large unit with a concentration of in-house design work.

2) Organization 10, the least efficient large unit with a concentration of in-house design work.

3) Organization 12, the efficient small unit with a concentration of in-house design work.

4) Organization 23, the least efficient small unit with a concentration of in-house design work.

5) Organization 24, the efficient large unit with design work contracted out to A-E firms.

6) Organization 32, the least efficient large unit with design work contracted out to A-E firms.

7) Organization 35, the efficient small unit with design work contracted out to A-E firms.

8) Organization 46, the least efficient small unit with design work contracted out to A-E firms.

Preparation of Data for Analysis. The computer code for CFA was developed and tested at the University of Texas at Austin, and is maintained on that school's CDC Dual Cyber 170/750. The code is written in Fortran and employs a revised primal simplex code (7:1). The authors traveled to the University of Texas at Austin and were permitted to use the Cyber and the CFA Code in the analysis of their data.

Use of the CFA code required preparation of the data in the proper format, as outlined in the paper by Bessent, Bessent, Clark, and Elam describing the code (7:6). The data from each of the fifty-two units was entered in the Aeronautical Systems Division (ASD) Cyber computer at Wright-Patterson Air Force Base, Ohio. A hard-copy of the data file was printed and all data entries were checked for accuracy against the original data list. The data file was then routed to a card printer, where the data was punched onto computer cards (four cards per organization). The cards were then entered into a card reader to verify that the data items had been punched accurately.

Upon arrival at the University of Texas at Austin, the researchers were given a briefing on the use of the school's Cyber computer and the CFA code. The data card deck and appropriate control cards were entered into the computer to establish a local data file. Some data cards could ot be read properly by the school's card reader, requiring some additional manual data input. A copy of the data file is contained in Appendix E.

IV. Findings and Results

The data file in Appendix E was analyzed using the CFA code contained in the University of Texas at Austin's Dual Cyber computer. The analysis runs were made the week of 25-28 June, 1984.

After entry of the execution command for the CFA code, the code instructs the user to specify requirements of the analysis from five options. First, the code asks which organizational units are to be included in the reference set to be analyzed. The authors requested all organizations be included in each run. Second, the code asks which organizations of the reference set are to be processed. Again, we specified all organizations be processed. The next two options ask which outputs and which inputs, respectively, are to be included in the analysis. Finally, the code asks which of the managerial reports, if any, are to be produced in the analysis. After the five options are specified, the program executes.

Initial runs on the data set were unsuccessful. Consultations with Dr. A. Bessent and Dr. W. Bessent, Co-Directors of the Educational Productivity Council (which supports the research and maintenance of the CFA code), revealed that the CFA code was dimensioned such that a combination of only twenty (20) inputs and outputs could be used. Dr. A. Bessent attempted to redimension the code so that up to 100 inputs and outputs could be analyzed, but her efforts were unsuccessful.

Since one of the options of the code is to select which inputs and outputs are to be considered, the authors then selected a total of twenty of the inputs and outputs for analysis. Again, the computer computation was aborted. Subsequent tests with succeedingly smaller combinations of inputs and outputs resulted in a successful run when a total of fifteen factors were considered.

Inputs and Outputs Used

Originally both the productivity of design engineers and the site development personnel were to be included in the measurement model. However, limitations of the computerized model required a reduction in the inputs and outputs. The site development personnel were eliminated from both the inputs and outputs. This resulted in total elimination of the following outputs:

-Number of surveys conducted.

-Total hours of surveys completed.

The list of inputs and outputs were still too numerous for the computerized version of CFA at the University of Texas. To eliminate inputs and outputs further it was determined to begin with those that have the smallest percentage of manhours devoted to them. To determine this the authors used data obtained from the AFIT School of Civil Engineering and presented in the School's Engineering and Environmental Planning Management Applications Course. This method resulted in the elimination of the following inputs:

-Number of professional education courses completed.

-One over the number of additional duties performed.

and the following outputs:

-Total O&M minor construction funds obligated.

-Total number of facility inspections and utility system surveys completed.

-Total number of special technical studies and reports completed.

-Pages of project specifications.

-Total number of oral presentations made.

-Number of pages of engineering drawings completed.

The final output eliminated was "Total A-E design funds obligated." It was eliminated because of indecision on the part of the authors whether it was truly an output or an input. Rather than jeapordize the analysis by including it as an output, it was eliminated entirely. This was possible since the A-E contract output portion is captured in the output,"Total estimated dollar amount of architect-engineer packages prepared."

That reduction left a total of four inputs and eleven outputs. The CFA model was able to accommodate that number of factors. These inputs and outputs, then, were used in the final analysis:

Inputs

1. Labor manhours
2. Labor costs
3. Years experience
4. Personnel skill level

Outputs

1. Total contract funds obligated

2. Estimated dollar amount of all projects designed (complete and ready for contracting action)

3. Total O&M maintenance and repair project funds obligated

4. Total number of projects designed (complete and ready for contracting action)

5. One over total funds expensed on contract change orders

6. One over number of contract change orders

7. Total estimated dollar amount of in-house work orders designed

8. Total estimated dollar amount of architect-engineer packages prepared

9. Estimated dollar amount of MCP Project Books

10. Number of work orders reviewed and/or evaluated

11. Number of technical reviews accomplished on designed projects

Model Execution

The computerized model was run with all 52 organizations and the 4 inputs and 11 outputs. The following results were obtained:

1. Organization 1, the efficient large unit with a concentration of in-house design work.

2. Organization 10, the least efficient large unit with a concentration of in-house design work.

3. Organization 12, the efficient small unit with a concentration of in-house design work.

4. Organization 23, the least efficient small unit with a concentration of in-house design work.

5. Organization 24, the efficient large unit with design work contracted out to A-E firms.

6. Organization 32, the least efficient large unit with design work contracted out to A-E firms.

7. Organization 35, the efficient small unit with design work contracted out to A-E firms.

8. Organization 46, the least efficient small unit with design work contracted out to A-E firms.

This coincides with the results anticipated in the methodology chapter of this research. The efficiencies of all 52 organizations are listed in Appendix F. The actual computer printout results are included in Appendix G.

The model gives two efficiencies. These are termed as the upper and lower bound efficiencies. The upper bound is the largest relative efficiency possible for that organization and the lower bound is the smallest possible relative efficiency for that organization. The actual efficiency may lay anywhere within these two bounds.

The indication of only four efficient organizations would lead us to believe that in fact four "neighborhoods" or divisions were used by the model as was desired. This means that small in-house design organizations were only evaluated against small in-house design organizations, etc.

The model also gives reports for each inefficient organization showing what inputs would be necessary for that organization to be efficient if it maintained the same output. The model also determines what output increases are necessary for an organization to become efficient if its present inputs remain the same. A sample of each report is included in Appendix H.

Limitations of the CFA Code

Use of the CFA code as it presently exists revealed some limitations which anyone interested in application of the code or further research in this area should take note of. Improvements to the CFA code are being made continuously, so some of the following problems may not be of concern in the near future.

In the development of the code, the case of a set of inputs and outputs exceeding twenty in number was unforeseen. The CFA code will not work for a case with more than twenty inputs and outputs. Depending on the data and its range, the code may not work with more than fifteen factors involved. Work is underway to expand the capability of the code in this regard. Until the problem is resolved, researchers are forced to minimize the number of inputs and outputs used. Pearson's correlation can be used on actual data to discard those factors having a high positive correlation (meaning one of the factors is sufficient to measure the activity) or those having a negative correlation (meaning additional amounts of that factor detract from productivity). Pearson's correlation was not used in this research effort to reduce the set of inputs and outputs because the data was generated by the researchers. Any highly positive or negative correlations would be suspect.

Related to the above problem, it may be advantageous in the description of an organization's productivity to first focus on a few main inputs and outputs in the analysis. After successful analyses have been made of those few factors, the researcher can expand and become more descriptive with each input and output. Additionally, select only those inputs and outputs having a positive correlation. While factors negatively correlated with productivity can be converted by using reciprocals or inverses, these manipulations tend to cause computation problems during program execution by generating extremely small numbers.

V. Conclusions and Recommendations

Conclusions

The measurement of productivity in an Air Force Civil Engineering Design Section is desirable from a management perspective. Until now, inadequate measurement techniques prevented managers from knowing how well their units were performing over time or with respect to other units. The use of the Constrained Facet Analysis technique can provide that information. CFA is a valid method of determining the relative efficiency of a base level Civil Engineering Design Section.

This research effort is a step forward in the DOD and Air Force Productivity Programs. Further research is needed to develop CFA's full potential of helping managers better understand productivity and improve organizational performance.

Research Questions Answered

Three research questions were presented in Chapter I of this thesis. In this section, each of the three questions are reiterated along with a brief summation of their respective answers.

The first research question posed in this thesis was, "What are the inputs and outputs for a base level Civil Engineering Design Section?" The total list of twenty outputs and six inputs described in the Methodology chapter of this research are the inputs and outputs for a Design Section. The complete list could not be used in the Constrained Facet Analysis technique used by the researchers for the development of the model, however, due to computer limitations. A reduction of relatively insignificant and/or redundant measures was made to meet the computer requirements.

The second research question asked, "What is the appropriate productivity measurement technique?" Three different analysis methods were examined, after which Constrained Facet Analysis was chosen. CFA is the only technique capable of handling multiple inputs and outputs and producing a single aggregate measure relative to a frontier of actual achievement.

The final research question asked, "Can a model of productivity be developed using appropriate inputs and outputs?" A model was developed, using the framework of the CFA model adapted to a Civil Engineering design context through the use of the Design Section inputs and outputs. Based on the results of the data analysis (presented in Chapter IV), the adaptation yielded a valid productivity measurement model.

Recommendations

The authors recommend that further research be done before any attempt is made to implement CFA into design sections. Actual data should be collected from the Continental United States (CONUS) Air Force bases. Pearson's correlations should be conducted for each input and output to screen out those factors that are redundant measurements or negatively correlated. The data should then be analyzed using CFA. Assuming that further research supports the notion that valid productivity measurement within design sections is possible, then we recommend implementation of the model.

We recommend that, should this analysis technique be implemented, design section managers be trained in its use and application, and in its limitations. The managers should be shown how it can help them improve their organization's performance, rather than becoming another mandated program that impedes their progress.

We recommend that any application of the CFA technique be done initially as an aid to the base level managers, rather than as an organizational assessment tool used at the Major Command level. Results of the analysis should be given to the base level managers for their use in effecting change to improve their organization. The analysis results would include the overall efficiency rating of the particular organization, summary reports of which inputs to decrease or outputs to increase to become efficient, and a list of the organizations against which they were compared. Armed with that information, the manager could then change those factors over which he has control to move his organization closer to the efficiency frontier. He can contact those units within the frontier "neighborhood" to see what those organizations are doing that makes them efficient. Additionally, he can identify those factors beyond his control which are contributing to his inefficiency rating, and possibly use the ratings to induce upper management to change those inputs and outputs in his favor.

As with any computer-generated product, the results are only as good as the information used. As numbers cannot totally desribe a situation, managerial common sense must enter into the evaluation. Each inefficiency rating requires investigation into the circumstances surrounding that organization's poor score. An inefficient rating can identify an organization needing improvement, but that rating may not be a valid assessment of the manager's efforts or problems. A poor manager can inherit an efficient organization, just as an excellent manager can find himself in an extremely inefficient unit. While measurements over time could yield information on a given manager's performance, a single evaluation cannot. Therefore, we would not recommend that the results of the model be used as an evaluation technique for managers.

Appendix A: CFA Model

Model Used in Constrained Facet Analysis of Not-Fully-Enveloped Units [8:16-19]

The model used in the iterative method called Constrained Facet Analysis is presented in this appendix, a model which can be used in evaluating the range of inefficiency in organizational units and in determining marginal rates of substitution and productivity in frontier facets.

Suppose one wishes to evaluate the relative efficiency of n decision making units (DMUs), each of which uses varying amounts of m inputs and produces varying amount of s outputs. Using notation conventions similar to those used by Clark (see references at the end of this appendix), let:

x_{ij} = the amounts of input type i used by DMU j during the period of observation, $i = 1,2,\ldots,m$ and $j = 1,2,\ldots,n$.

y_{rj} = the amount of output type r produced by DMU j during the period of observation, $r = 1,2,\ldots,s$ and $j = 1,2,\ldots,n$.

x_{ik} = the amount of input type i used by the unit k where $k \quad j = \{1,2,\ldots,k,\ldots,n\}$ and unit k is the DMU being evaluated. Each DMU in turn will be evaluated.

y_{rk} = the amount of output type r used by DMU_k.

N = $1,2,3,\ldots,M$ is the sequence of iterations of the Constrained Facet Analysis model which ends at iteration M.

$h_k^{(1)}$ = the upper bound efficiency value sought for DMU_k which is determined from the solution of the first iteration of the Constrained Facet Analysis.[1]

$h_k^{(M)}$ = the lower bound efficiency value sought for DMU_k which is determined from the solution of the final iteration (M) of the Constrained Facet Analysis.

$\nu_{ik}^{(N)}$ = the multipliers for each <u>input</u> type i which will be determined by solution of the Nth iterative model.

$\mu_{rk}^{(N)}$ = the multipliers for each <u>output</u> type r which will be determined by solution of the Nth iterative model.

$s_{rk}^{(N-1)*}$ = the dual surplus values associated with outputs $r = 1,2,\ldots,s$ of DMU_k at optimality of the previous iteration. For the initial iteration, these surplus values are

$$s_{rk}^{(N-1)*} = s_{rk}^{(0)*} = y_{rk}.$$

$s_{ik}^{(N-1)*}$ = the dual surplus values associated with inputs $i = 1,2,\ldots,m$ at optimality of the previous iteration. Initial values at iteration one are

$$s_{ik}^{(N-1)*} = s_{ik}^{(0)*} = x_{ik}.$$

[1] The form of the CFA model used in the first iteration is similar to the Data Envelopment Analysis (DEA) model of Charnes, Cooper and Rhodes [1], however, the non-Archimedean infinitesimal quantities are not required.

The following linear programming model is used in constrained facet analysis for each iteration $N = 1, 2, \ldots M$:

Primal

$$\text{Max} \quad f_k^{(N)} = \sum_{r=1}^{s} \mu_{rk}^{(N)} s_{rk}^{(N-1)*} + \sum_{i=1}^{m} \nu_{ik}^{(N)} s_{ik}^{(N-1)*} \tag{1}$$

$$\text{s.t.} \quad \sum_{r=1}^{s} \mu_{rk}^{(N)} y_{rj} - \sum_{i=1}^{m} \nu_{ik}^{(N)} x_{ij} = 0 \quad \text{for } j \in E_k^{(N)}$$

$$\sum_{r=1}^{s} \mu_{rk}^{(N)} y_{rj} - \sum_{i=1}^{m} \nu_{ik}^{(N)} x_{ij} \leq 0 \quad \text{for } j \in \bar{E}_k^{(N)}$$

$$\sum_{i=1}^{m} \nu_{ik}^{(N)} x_{ik} = 1$$

$$\mu_{rk}^{(N)}, \nu_{ik}^{(N)} > 0$$

where

$E_k^{(N)} \equiv$ {j/jth constraint holds with equality at optimality at iteration N-1}

$\bar{E}_k^{(N)} \equiv$ {j/jth constraint is < 0 at optimality of iteration N-1}

$E_k^{(1)} \equiv \phi$ (empty), $\bar{E}_k^{(1)} \equiv \{1, 2, \ldots, n\}$.

The upper and lower bound efficiency measures are obtained from solution of the first and last iterative models as shown below:

$$h_k^{(1)} = f_k^{(1)} - 1 = \sum_{r=1}^{s} \mu_{rk}^{(1)*} y_{rk}$$

$$h_k^{(M)} = \sum_{r=1}^{s} \mu_{rk}^{(M)*} y_{rk}$$

The dual of model (1) above is:

<u>Dual</u>

$$\text{Min } \omega_k^{(N)} \tag{2}$$

$$\text{s.t.} \quad \sum_{j \in E^{(N)}} \lambda_j^{(N)} y_{rj} + \sum_{j \in \bar{E}^{(N)}} \gamma_j^{(N)} y_{rj} - s_{rk}^{(N)}$$

$$= s_{rk}^{(N-1)*} \qquad r = 1,2,\ldots,s$$

$$x_{ik}\omega_k^{(N)} - \sum_{j \in E^{(N)}} \lambda_j^{(N)} x_{ij} - \sum_{j \in \bar{E}^{(N)}} \gamma_j^{(N)} x_{ij} - s_{ik}^{(N)}$$

$$= s_{ik}^{(N-1)*} \qquad i = 1,2,\ldots,m$$

$$\omega_k^{(N)},\ \lambda_j^{(N)} \text{ unrestricted;} \quad \gamma_j^{(N)},\ s_{rk}^{(N)},\ s_{ik}^{(N)} \geq 0$$

The mathematical theory and proofs related to the development of this model can be found in Clark [2] and will not be repeated in this appendix. But there are a few model characteristics which are worth noting here.

First, the efficiency measures $h_k^{(1)}$ and $h_k^{(M)}$ are scalar ratio measures. Secondly, the constraints of the primal problem insure that the maximum achievable value of these efficiency measures is 1. Furthermore, Constrained Facet Analysis does not require that outputs or inputs have common scales or units of measurement, an important attribute when dealing with difficulties such as nonmonetary objectives and nonpurchased resources. However, all measured input and output values are required to be strictly positive. Finally, each unit is compared to others in the set which have similar input/output mixes, i.e., those units in its "neighborhood."

In short, the Constrained Facet Analysis model can identify units which are efficient or inefficient relative to a neighborhood frontier region of actual achievement; it can provide a limited number of clues on possible causes from analysis of surplus variables and multipliers; and it is helpful in evaluating the impact of alternative mixes of inputs and outputs.

Furthermore, the information provided by the CFA model is a major improvement over the inadequate, partial (and sometimes inaccurate) measures of performance which are now typically in use in many public service organizations. In addition to its usefulness as a performance monitoring device, this efficiency analysis tool opens the door for further development and growth in other areas of planning, resource allocation and decision support.

Appendix References

1. Charnes, A., W.W. Cooper and E. Rhodes. "Measuring the Efficiency of Decision Making Units," European Journal of Operational Research: 429-444 (1978).

2. Clark, C. Terry. Data Envelopment Analysis and Extensions for Decision Support and Management Planning. Unpublished doctoral dissertation. Graduate School of Business, University of Texas at Austin, Austin TI, May 1983.

Appendix B: Panel Members

Panel of AFIT School of Systems and Logistics

Engineering Management Students

NAME/RANK	CUM YEARS IN BCE
James T. Ryburn, Captain	9
Frederick Nightengale, Captain	6
Charles Howell, Captain	8

Panel of AFIT School of Civil Engineering

Faculty

NAME/RANK	POSITION
Jeffery R. Charles, Captain	Course Director, Dept of Management Applications
Thomas H. Gross, Major	Course Director, Dept of Management Applications

Appendix C: List of Inputs and Outputs Analyzed

OUTPUT MEASURES	REASON FOR ELIMINATION
1. Total estimated dollar amount of contract projects and in-house work orders designed	This is the addition of output measures 2 and 12
2. Total contract funds obligated	
3. Total O&M contract funds obligated	
4. Total O&M maintenance and repair funds obligated	
5. Total O&M minor construction funds obligated	
6. Total estimated dollar amount of project document (DD 1391/1391C) completed	DD 1391/1391C are the responsibility of DEEV
7. Total number of projects designed (complete and ready for acquisition action)	
8. Total number of facility inspections and utility system surveys completed	
9. Total number of special technical studies and reports completed	
10. One over total funds expensed on contract change orders	
11. One over number of contract change orders	
12. Total estimated dollar amount of in-house work orders designed	
13. Total service contract funds obligated	Service contracts are handled by DEEC

14. Number of environmental assessments (EA´s) and environmental impact statements (EIS´s) completed	While assistance may be given, EA´s and EIS´s are accomplished by DEEV
15. Total estimated dollar amount of architect-engineer packages prepared	
16. Total A-E design funds obligated	
17. Number of work orders reviewed and/or evaluated	
18. Number of technical reviews accomplished on designed projects	
19. Number of military family housing (MFH) inspections completed	To avoid counting the inspections accomplished by the Housing Office, those completed by DEEE will be added in output 8.
20. Pages of project specifications	
21. Total hours of supplemental training completed	Evaluated as both an input and an output and not considered to be a significant amount at a base level organization
22. Number of professional educational courses completed	Was originally evaluated as an output, but in the opinion of the researchers should be included as an input instead
23. Total hours construction inspections completed	Construction inspections are handeled by DEEC. Those that are completed by DEEE will be included in output 8
24. Total number of oral presentations made	

25. Total number of journal articles written	Not part of military job. If accomplished, should be completed on individual time
26. Hours of training sessions taught/conducted	Not considered to be a significant amount in a base level organization
27. Number of surveys conducted	
28. Total hours of surveys completed	
29. Number of pages of engineering drawings (blueprints) completed	
30. Customer satisfaction index	Time lag between facility design and customer use is too long
31. Number of buildings demolished	Engineers are not always involved. Could be performed on a service contract handled strictly by DEEC
32. Estimated dollar amount of all projects designed (completed and ready for acquisition action)	
33. Estimated dollar amount of MCP Project Books	

INPUT MEASURES	REASON FOR ELIMINATION
1. Labor manhours	
2. Labor costs	
3. Years experience	
4. Personnel skill level aggregate	
5. Number of professional education courses completed	
6. One over additional duties performed	

Appendix D: Inputs and Outputs Further Defined

All outputs and inputs are cumulative values for all personnel in design (those figured into the manhours calculation) for the fiscal year. Data could be broken down into quarterly figures and used in the productivity model, if desired.

OUTPUTS FURTHER DEFINED

1. Total contract funds obligated- The total amount of design contract funds obligated. Outputs 3, 4, and 10 are subsets of output 1. Should also include Military Construction Program (MCP) and Military Family Housing.

2. Estimated dollar amount of all projects designed- All projects designed during the year that are complete and ready for contracting action. This output should also measure the "on the shelf" effort during the year.

3. Total O&M maintenance/repair project funds obligated- Total maintenance and repair project funds. This should be the majority of work and funds.

4. Total O&M minor construction funds obligated- Should be a small percentage of output 1.

5. Total number of projects designed (complete and ready for contracting action)- This should be the number of those projects included in output 2. This measure of quantity will prevent one large project from dominating as could be the case in output 2.

6. Total number of facility inspections, utility system surveys and construction site inspections completed- This should include the yearly facility inspections where the engineer accompanies a planner, utility system surveys that the engineers may be involved with and also construction site inspections. The construction site inspections should be in support of or along with construction management.

7. Total number of special technical studies and reports completed- This should include any cost savings studies, replacement vs repair studies etc. There is a trend in the Air Force toward increased emphasis in this area.

8. One over total funds expensed on contract change orders- By taking the reciprocal value, we are preventing an increase in change order funds to also increase productivity. This output is attempting to measure quality of the designs accomplished.

9. One over the number of contract change orders- This recipocal is to prevent one large change order from dominating as can be done in output 8.

10. Total estimated dollar amount of in-house work orders designed- This is the estimated dollar amount of projects designed to be completed by the in-house work force. Those projects are accomplished by Civil Engineering Operations Branch personnel (DEM).

11. Total estimated dollar amount of architect-engineer packages prepared- The estimated dollar amount of projects that the engineer must prepare prior to submission to an architect-engineer firm.

12. Total Architect-Engineer design funds obligated- The amount of Title I-B design funds obligated to an Architect-Engineer firm.

13. Estimated dollar amount of MCP Project Books- The estimated dollar amount of those Military Construcion Program Project Books prepared by the design section. This value may be zero if MCP PB's are prepared by Environmental Planning Section.

14. Number of work orders reviewed and/or evaluated- The number of work orders that the engineers render assistance on, advise or review for the DEM personnel

15. Number of technical reviews accomplished on designed projects- Should include the 35% review, the 60-65% review and the 95% review. Include only those reviews actually accomplished.

16. Pages of project specification- The number of pages of specifications written by the design section personnel. Should not include the pages added by Base Contracting.

17. Total number of oral presentations made- Should include presentations such as paintplan, special command interest projects and presentations to MAJCOM personnel. Should not include daily or weekly standups.

18. Number of surveys conducted- The number of site surveys conducted by the site development personnel. Should also include plane crash surveys.

19. Total hours of surveys completed- The manhours expended in performing the surveys listed in output 18. This measure is to help take into account a large plane crash survey that might be accomplished.

20. Number of pages engineering drawings completed- Those drawings done by the site development personnel and engineers in project design. To include updating of as-built drawings if performed by the engineers or site development personnel.

INPUTS FURTHER DEFINED

1. Labor manhours- The gross manhours available during the year assuming an eight hour day, five day week work week. The figure is 2080 hours a year per person. Supervisory personnel are included in the figure.

2. Labor costs- Figured using the base shop rate times the gross manhours.

3. Years experience- The cumulative total years of engineering experience of personnel in design. A scale weighting the type of experience could be used, but would be extremely hard to administer. If all organizations use the same criteria, a weighted scale would not be necessary.

4. Personnel skill level aggregate- A numeric total of points assessed for the personnel skill level according to the following point values:

GS-7	3	AB-A1C	1	LT	4
GS-9	4	SRA-SSGT	2	CAPT	5
GS-11	5	TSG-MSG	3	MAJOR	6
GS-12	5.5	SMSG-CMSG	4		
GS-13	6				

One additional point will be added if the individual is a licensed professional engineer. An additional .5 will be added if the individual possesses an advanced degree.

5. Number of professional education courses completed- Courses sponsored by AFIT, civilian university or professional organization. Conventions and seminars should also be included.

6. One over the number of additional duties- This is to account for the decrease in resources available to perform work when personnel are involved in additional duties.

Appendix E: Data

This appendix contains the printout of the data file used by the Constrained Facet Analysis model in determining the efficiencies for the organizations. At the top of the printout is the title assigned to the model (for computer file identification purposes) by the authors. This is followed by a line that contains three numbers. The first number is the number of organizations in the data file. The second number is the number of outputs and the last number is the number of inputs. The output and input titles are then printed out. This order is important, as it is in the same order that the data is listed within each organization. Each organization's data requires four lines on the printout. The organization numbers are printed on the left hand side of the page. This data is supplied for any future researchers that may attempt to replicate the model and result.

BASE CIVIL ENGR DESIGN SECTION PROD

52 20 6

OUTPUT 01 OUTPUT 02 OUTPUT 03 OUTPUT 04 OUTPUT 05 OUTPUT 06 OUTPUT07
OUTPUT 08 OUTPUT 09 OUTPUT 10 OUTPUT 11 OUTPUT 12 OUTPUT 13 OUTPUT14
OUTPUT 15 OUTPUT 16 OUTPUT 17 OUTPUT 18 OUTPUT 19 OUTPUT20 INPUT 01
INPUT 02 INPUT 03 INPUT 04 INPUT 05 INPUT 06

01							
01	5.6	7.8	3.8	1.	128.	300.	12.
01	5.	.05	1.2	1.	0.9	2.8	232.
01	300.	2500.	17.	36.	900.	650.	100.
01	1500.	300.	250.	10.	8.		
02							
02	5.2	7.7	3.6	0.9	126.	240.	11.
02	2.5	.04	1.1	0.9	0.9	2.7	220.
02	250.	2400.	16.	27.	700.	625.	115.
02	2000.	380.	330.	11.	9.		
03							
03	5.0	6.8	3.4	0.8	122.	251.	11.
03	3.33	.033	1.1	1.	0.8	2.5	150.
03	240.	1600.	17.	35.	600.	575.	117.
03	1600.	390.	260.	12.	10.		
04							
04	4.8	7.5	3.7	0.85	119.	298.	10.
04	1.428	.0286	0.95	1.0	0.8	2.4	160.
04	280.	2000.	16.	24.	500.	550.	110.
04	1500.	400.	250.	11.	8.		
05							
05	4.6	7.6	2.9	0.75	112.	278.	12.
05	1.67	.025	1.0	0.9	0.9	2.8	210.
05	290.	1800.	13.	36.	900.	525.	112.
05	1700.	370.	270.	10.	11.		
06							
06	4.7	7.7	3.5	0.88	127.	274.	9.
06	1.428	.0238	0.9	1.0	0.8	2.5	230.
06	300.	1700.	15.	28.	700.	650.	122.
06	1800.	420.	280.	12.	10.		
07							
07	4.9	7.8	3.7	0.9	128.	298.	10.
07	1.053	.037	0.9	0.9	0.9	2.0	210.
07	220.	2200.	14.	35.	900.	600.	124.
07	1900.	320.	290.	13.	9.		
08							
08	5.1	7.6	3.6	0.94	98.	264.	9.
08	1.111	.0263	0.8	0.8	0.7	2.7	170.
08	240.	2300.	12.	29.	800.	500.	114.
08	2100.	340.	320.	14.	8.		
09							
09	4.4	7.4	3.5	0.97	124.	222.	8.
09	1.0	.0238	0.85	0.8	0.8	2.2	180.
09	200.	1700.	11.	31.	600.	475.	120.
09	2200.	410.	310.	15.	9.		
10							
10	4.3	6.8	2.7	0.7	110.	220.	8.
10	0.953	.0222	0.9	0.8	0.7	2.0	150.
10	200.	1500.	10.	25.	500.	450.	125.
10	2240.	420.	330.	17.	12.		
11							
11	4.7	7.4	3.5	0.8	122.	250.	8.
11	0.909	.0244	1.0	0.9	0.7	2.1	200.
11	290.	2400.	15.	34.	800.	500.	100.

```
ORG 11   2200.    400.     300.     16.      11.
ORG 12
ORG 12   3.       4.       1.3      0.45     70.      100.     5.
ORG 12   100.     0.125    0.8      3.       2.7      1.5      100.
ORG 12   100.     1000.    9.       20.      200.     240.     40.
ORG 12   500.     80.      80.      3.       2.
ORG 13
ORG 13   1.2      3.9      1.2      0.14     32.      90.      3.
ORC 13   50.      .0714    0.7      2.7      2.5      1.3      .
ORG 13   90.      900.     8.       8.       160.     140.     .
ORG 13   900.     180.     100.     7.       5.
ORG 14
ORG 14   1.8      2.4      1.1      0.18     50.      29.      5.
ORG 14   33.33    0.111    0.6      2.8      2.6      1.5      52.
ORG 14   95.      600.     9.       5.       100.     150.     40.
ORG 14   800.     170.     110.     6.       3.
ORG 15
ORG 15   1.6      2.       1.       .22      37.      80.      4.
ORG 15   25.      .0833    .8       2.9      2.7      1.3      60.
ORG 15   100.     500.     6.       7.       80.      160.     42.
ORG 15   700.     160.     120.     5.       2.
ORG 16
ORG 16   2.       3.8      .9       .25      40.      30.      2.
ORG 16   20.      .125     .7       3.       2.6      1.       90.
ORG 16   95.      1000.    7.       9.       70.      170.     44.
ORG 16   600.     150.     130.     4.       3.
ORG 17
ORG 17   2.2      1.5      .8       .29      42.      40.      3.
ORG 17   16.67    .0714    .5       2.9      2.5      1.2      80.
ORG 17   85.      600.     8.       11.      90.      180.     46.
ORG 17   500.     140.     140.     3.       4.
ORG 18
ORG 18   2.4      2.5      1.3      .31      29.      100.     2.
ORG 18   14.286   .0769    .8       2.5      2.7      1.1      92.
ORG 18   90.      900.     9.       13.      110.     140.     48.
ORG 18   550.     130.     150.     4.       5.
ORG 19
ORG 19   2.6      2.8      1.2      .35      30.      90.      5.
ORG 19   12.5     .0833    .6       2.4      2.6      1.5      70.
ORG 19   85.      700.     6.       15.      130.     200.     50.
ORG 19   650.     120.     160.     5.       4.
ORG20
ORG20    2.8      2.9      1.1      .37      45.      50.      4.
ORG20    14.286   .0909    .7       2.6      2.5      1.4      80.
ORG20    80.      800.     7.       16.      150.     210.     52.
ORG20    750.     110.     170.     6.       3.
ORG 21
ORG 21   3.       3.       1.       .39      70.      60.      5.
ORG 21   10.      .1       .8       2.3      2.3      1.1      60.
ORG 21   90.      700.     8.       17.      170.     220.     54.
ORG 21   850.     100.     110.     7.       2.
ORG 22
ORG 22   2.8      1.8      .7       .41      55.      80.      4.
ORG 22   100.     .111     .4       2.4      2.[illegible]  1.2   70.
ORG 22   75.      800.     7.       18.      180.     230.     56.
ORG 22   900.     90.      100.     5.       4.
ORG 23
ORG 23   1.2      1.5      .3       .1       27.      29.      2.
ORG 23   10.      .0667    .3       2.3      2.2      1.       52.
ORG 23   75.      450.     6.       4.       50.      125.     63.
ORG 23   900.     200.     120.     7.       5.
ORG 2[illegible]
```

ORG 24	5.6	7.8	2.9	1.	128.	300.	12.
ORG 24	5.	.05	1.2	3.	2.7	2.8	232.
ORG 24	300.	2500.	17.	36.	900.	650.	100.
ORG 24	1500.	300.	250.	10.	8.		
ORG 25							
ORG 25	5.2	7.7	2.6	.9	126.	240.	11.
ORG 25	2.5	.04	1.1	2.7	2.5	2.7	220.
ORG 25	250.	2400.	16.	27.	700.	625.	115.
ORG 25	2000.	380.	330.	11.	9.		
ORG 26							
ORG 26	5.	6.8	2.4	.8	122.	251.	11.
ORG 26	3.333	.0333	1.1	2.8	2.6	2.5	150.
ORG 26	240.	1600.	17.	35.	600.	575.	117.
ORG 26	1600.	390.	260.	12.	10.		
ORG 27							
ORG 27	4.8	7.5	2.7	0.85	119.	298.	11.
ORG 27	1.428	.0286	0.95	2.9	2.7	2.4	160.
ORG 27	280.	2000.	16.	24.	500.	550.	110.
ORG 27	1500.	400.	250.	11.	8.		
ORG 28							
ORG 28	4.6	7.6	1.9	0.75	112.	278.	12.
ORG 28	1.667	.025	1.0	3.0	2.7	2.8	210.
ORG 28	290.	1800.	13.	36.	900.	525.	112.
ORG 28	1700.	370.	270.	10.	11.		
ORG 29							
ORG 29	4.7	7.7	2.5	0.88	127.	274.	10.
ORG 29	1.428	.0238	0.9	2.9	2.6	2.3	230.
ORG 29	300.	1700.	15.	28.	700.	650.	122.
ORG 29	1800.	420.	280.	12.	10.		
ORG 30							
ORG 30	4.9	7.8	2.7	0.9	128.	288.	9.
ORG 30	1.053	.037	0.9	2.5	2.5	2.0	210.
ORG 30	220.	2200.	14.	33.	900.	600.	124.
ORG 30	1900.	320.	280.	13.	9.		
ORG 31							
ORG 31	5.1	7.6	2.6	0.97	124.	264.	9.
ORG 31	1.	.0263	0.8	2.6	2.4	2.7	170.
ORG 31	240.	2300.	12.	29.	800.	500.	114.
ORG 31	2100.	340.	320.	14.	8.		
ORG 32							
ORG 32	4.3	6.8	1.7	0.7	110.	220.	8.
ORG 32	0.833	.0222	0.8	2.5	2.3	2.0	150.
ORG 32	200.	1500.	10.	25.	500.	450.	125.
ORG 32	2240.	420.	330.	17.	12.		
ORG 33							
ORG 33	4.7	7.4	2.5	0.94	122.	250.	8.
ORG 33	0.909	.0244	0.85	2.7	2.3	2.2	190.
ORG 33	200.	1700.	11.	31.	600.	475.	120.
ORG 33	2200.	410.	310.	15.	9.		
ORG 34							
ORG 34	4.4	7.4	2.5	0.8	126.	222.	12.
ORG 34	1.111	.0238	1.	2.8	2.7	2.1	200.
ORG 34	280.	2400.	15.	34.	900.	500.	100.
ORG 34	2200.	400.	300.	16.	11.		
ORG 35							
ORG 35	3.	4.	7.3	0.45	70.	100.	5.
ORG 35	100.	0.125	0.8	2.	1.5	1.5	100.
ORG 35	100.	1000.	9.	20.	200.	240.	40.
ORG 35	500.	80.	90.	3.	2.		
ORG 36							
ORG 36	1.2	3.9	1.2	0.14	32.	90.	3.
ORG 36	50.	0.111	0.7	1.1	3.8	1.3	90.

ORG 36	90.	900.	8.	8.	160.	140.	60.	
ORG 36	900.	180.	100.	7.	5.			
ORG 37								
ORG 37	1.8	2.4	1.1	0.18	50.	28.	5.	
ORG 37	33.33	0.1	0.6	1.2	0.9	1.5	52.	
ORG 37	95.	600.	9.	5.	100.	150.	40.	
ORG 37	800.	170.	110.	6.	3.			
ORG 38								
ORG 38	1.6	2.	1.	0.22	37.	80.	4.	
ORG 38	25.	.091	0.8	1.3	1.5	1.3	60.	
ORG 38	100.	500.	6.	7.	80.	160.	42.	
ORG 38	700.	160.	120.	5.	2.			
ORG 39								
ORG 39	2.	3.8	0.9	0.25	40.	30.	2.	
ORG 39	20.	.0833	0.7	1.4	1.2	1.	90.	
ORG 39	95.	1000.	7.	9.	70.	170.	44.	
ORG 39	600.	150.	130.	4.	3.			
ORG 40								
ORG 40	2.2	1.5	0.8	0.29	42.	40.	3.	
ORG 40	16.67	.0769	.5	1.5	.7	1.2	80.	
ORG 40	85.	600.	8.	11.	90.	180.	46.	
ORG 40	500.	140.	140.	3.	4.			
ORG 41								
ORG 41	2.4	2.5	1.3	.31	29.	100.	2.	
ORG 41	14.28	.0714	.8	1.6	1.1	1.1	92.	
ORG 41	90.	900.	9.	13.	110.	190.	48.	
ORG 41	550.	130.	150.	4.	5.			
ORG 42								
ORG 42	2.6	2.8	1.2	.35	30.	90.	5.	
ORG 42	12.5	.0667	0.6	1.7	1.0	1.5	70.	
ORG 42	85.	700.	6.	15.	130.	200.	50.	
ORG 42	650.	120.	160.	5.	4.			
ORG 43								
ORG 43	2.8	2.9	1.1	.37	45.	50.	4.	
ORG 43	11.11	.125	.7	1.8	1.3	1.4	80.	
ORG 43	80.	800.	7.	16.	150.	210.	52.	
ORG 43	750.	110.	170.	6.	3.			
ORG 44								
ORG 44	3.	3.	1.	.39	70.	60.	5.	
ORG 44	10.	.0833	.8	1.9	1.4	1.1	60.	
ORG 44	90.	700.	8.	17.	170.	220.	54.	
ORG 44	850.	100.	110.	7.	2.			
ORG 45								
ORG 45	2.8	1.8	.9	.41	55.	80.	4.	
ORG 45	100.	.111	.4	1.	1.5	1.2	70.	
ORG 45	75.	800.	7.	18.	180.	230.	56.	
ORG 45	800.	90.	100.	5.	4.			
ORG 46								
ORG 46	1.2	1.5	.8	.1	27.	28.	2.	
ORG 46	10.	.0667	.3	.8	.7	1.	52.	
ORG 46	75.	450.	6.	4.	50.	125.	60.	
ORG 46	900.	200.	180.	7.	5.			
ORG 47								
ORG 47	1.4	3.5	1.2	.43	65.	70.	3.	
ORG 47	20.	.0714	.5	.9	1.1	1.4	130.	
ORG 47	80.	900.	9.	19.	190.	130.	54.	
ORG 47	500.	190.	90.	6.	4.			
ORG 48								
ORG 48	2.4	2.5	1.3	.31	29.	100.	2.	
ORG 48	14.28	.0769	.9	2.5	2.7	1.1	92.	
ORG 48	90.	900.	9.	13.	110.	190.	48.	
ORG 48	550.	130.	150.	4.	5.			

ORG 49							
ORG 49	4.7	7.7	3.5	.88	127.	274.	9.
ORG 49	1.428	.0238	.9	1.	.8	2.3	230.
ORG 49	300.	1700.	15.	28.	700.	650.	122.
ORG 49	1800.	420.	290.	12.	10.		
ORG 50							
ORG 50	1.8	2.4	1.1	.18	50.	28.	5.
ORG 50	33.33	.111	.6	2.9	2.6	1.5	52.
ORG 50	95.	600.	9.	5.	100.	150.	40.
ORG 50	800.	170.	110.	6.	3.		
ORG 51							
ORG 51	4.4	7.4	2.5	.9	126.	222.	12.
ORG 51	1.11	.0238	1.	2.8	2.7	2.1	200.
ORG 51	290.	2400.	15.	34.	800.	500.	100.
ORG 51	2200.	400.	300.	16.	11.		
ORG52							
ORG52	2.2	1.5	.8	.29	42.	40.	3.
ORG52	16.67	.0714	.5	2.9	2.5	1.2	80.
ORG52	85.	600.	8.	11.	90.	180.	46.
ORG52	500.	140.	140.	3.	4.		

Appendix F: Organizational Efficiencies

Organizacion	Lower Bound	Upper Bound
1	1.000	1.000
2	.79136	.79136
3	.59427	.75203
4	.69733	.93149
5	.88892	.88892
6	.76336	.87833
7	.68393	.68393
8	.57143	.75729
9	.64095	.64095
10	.59284	.59284
11	.65909	.96655
12	1.000	1.000
13	.77934	.77934
14	.99906	.99906
15	.95138	.95138
16	.10667	.90812
17	.96564	.96564
18	.90801	.90801
19	.79891	.79891
20	.71702	.71702
21	.79896	.79896
22	.88870	.88870
23	.00000	.51027
24	1.000	1.000
25	.62500	.79137
26	.59427	.75204
27	.69733	.93150
28	.82038	.88893
29	.76336	.87834
30	.57895	.68394
31	.57143	.75732
32	.44643	.59285
33	.45455	.64096
34	.63636	.94871
35	1.000	1.000
36	.77929	.77929
37	.99901	.99901
38	.67227	.95132
39	.62500	.86267
40	.52147	.84910
41	.0000	.90798
42	.79888	.79888
43	.05228	.76813
44	.0000	.79893
45	.88867	.88867

Organization	Lower Bound	Upper Bound
46	.35714	.47489
47	.99893	.99893
48	.90801	.90801
49	.76336	.87833
50	.99906	.99906
51	.30706	.97160
52	.96564	.96564

Appendix G: Computer Printout of Results

This appendix contains a portion of the printout that is received as the result of a successful run of the Constrained Facet Analysis (CFA) model.[1] By itself, this printout is of marginal value to the manager. The manager should refer to the input and output reports. This printout permits the individual running the model to check for errors and consistency.

At the top of the printout is the title of the specific CFA model (i.e. the name of the data file) being run. This is followed by a line that contains three numbers. The first number is the number of organizations being evaluated, the second number is the number of inputs evaluated, and the third number is the number of inputs evaluated. The output and inputs titles are then printed out. This order is important as this is the same order the inputs and outputs are listed in the organizational data (the organization number is listed in the far left hand column) that follows. The first line of the organizational data is blank except for two numbers on the far right hand side. The first number is the lower bound efficiency and the second number is the upper bound efficiency. These values are listed separately in Appendix F.

[1]Results from the first 32 organizations are included. The printouts from organizations 33 to 52 were unsuitable for reproduction.

The output and input data follows on the next lines in the same order as listed in the header. Each output and input datum requires three lines. The top line repeats the actual observed value of that particular output or input, as found in the data file. The second line is the multiplier the model used in determining the relative importance of that output or input. The third line is the value of slack (output) or surplus (input) that is available in that organization for the observed values. An efficient organization has zero slack or surplus.

```
1              BASE CIVIL ENGR DESIGN SECTION PROD
2                 52    11     4
3              OUTPUT 01 OUTPUT 02 OUTPUT 03 OUTPUT 05 OUTPUT 08 OUTPUT 09 OUTPUT 10
4              OUTPUT 11 OUTPUT 13 OUTPUT14  OUTPUT 15 INPUT 01   INPUT 02  INPUT 03
5               INPUT 04
0 ORG 01                                                                 1.00000 1.00000
1 ORG 01          5.000      7.000      3.000    128.000      5.000          0     1.200
2 ORG 01        .000010    .040709    .000020    .000001    .000010    .000100   .000010
3 ORG 01              0          0          0          0          0          0         0
4 ORG 01          1.000      2.800    232.000    300.000    100.000   1500.000   300.000
5 ORG 01        .000010    .000010    .000001    .002117    .009993    .000000   .000001
6 ORG 01              0          0          0          0          0          0         0
7 ORG 01        250.000
8 ORG 01        .000001
9 ORG 01              0
0 ORG 02                                                                  .79136   .79136
1 ORG 02          5.200      7.700      3.000    126.000      2.500          0     1.100
2 ORG 02              0          0   -.000000          0          0          0         0
3 ORG 02           .800       .447          0     12.824    117.353       .141      .371
4 ORG 02           .900      2.700    220.000    250.000    115.000   2000.000   380.000
5 ORG 02        .000000          0    .002558    .000921    .008090          0         0
6 ORG 02              0       .300          0          0          0    335.078    74.000
7 ORG 02        330.000
8 ORG 02              0
9 ORG 02         57.225
0 ORG 03                                                                  .59427   .75203
1 ORG 03          5.000      6.800      3.400    122.000      3.330          0     1.140
2 ORG 03              0          0    .000000          0          0          0         0
3 ORG 03          2.300      2.759          0     62.529    153.771       .193      .700
4 ORG 03          1.000      2.500    150.000    240.000    117.000   1600.000   390.000
5 ORG 03       -.000000          0    .002514    .000905    .008547          0         0
6 ORG 03              0      1.150          0          0          0    249.170    39.047
7 ORG 03        260.000
8 ORG 03              0
9 ORG 03         50.725
0 ORG 04                                                                  .69733   .93149
1 ORG 04          4.800      7.500      3.700    119.000      1.428          0      .950
2 ORG 04              0          0    .000000          0          0          0         0
3 ORG 04          2.400      3.712          0     67.706    242.016       .304      .820
4 ORG 04          1.000      2.400    160.000    280.000    110.000   1500.000   400.000
5 ORG 04        .000000          0    .002674    .000963    .009091          0         0
6 ORG 04              0      1.200          0          0          0    354.011    50.952
7 ORG 04        250.000
8 ORG 04              0
9 ORG 04         67.316
0 ORG 05                                                                  .80092   .80092
1 ORG 05          4.600      7.600      2.900    112.000      1.670          0     1.000
2 ORG 05              0          0    .000000          0          0          0         0
3 ORG 05          1.317       .563          0     23.891     46.901       .054      .338
4 ORG 05           .900      2.000    210.000    290.000    112.000   1700.000   370.000
5 ORG 05       -.000000          0          0    .003067    .001534          0         0
6 ORG 05              0       .159     24.348          0          0     62.270    40.057
7 ORG 05        270.000
8 ORG 05        .003067
9 ORG 05              0
0 ORG 06                                                                  .76330   .57333
1 ORG 06          4.700      7.700      3.500    127.000      1.428          0      .900
2 ORG 06              0          0    .000000          0          0          0         0
3 ORG 06           .260      1.343          0     27.100     97.704       .125      .112
4 ORG 06          1.000      2.300    230.000    300.000    122.000   1500.000   420.000
5 ORG 06        .000000          0          0    .002545    .003017          0   .001272
```

6 ORG 06	0	.054	21.359	0	0	125.9[illegible]	[illegible]
7 ORG 06	280.000						
8 ORG 06	0						
9 ORG 06	39.695						
0 ORG 07						.50345	.00345
1 ORG 07	4.900	7.800	3.700	128.000	1.053	0	[illegible]
2 ORG 07	0	0	.000000	0	0	0	0
3 ORG 07	1.200	.382	0	13.941	175.505	.211	.044
4 ORG 07	.900	2.000	210.000	220.000	124.000	1900.000	320.000
5 ORG 07	0	0	.002372	.000054	.008065	0	0
6 ORG 07	0	1.050	0	0	0	283.321	54.035
7 ORG 07	290.000						
8 ORG 07	0						
9 ORG 07	[illegible].457						
0 ORG 08						.57143	.75723
1 ORG 08	5.100	7.600	5.000	98.000	1.111	0	.610
2 ORG 08	0	0	-.000000	0	0	0	0
3 ORG 08	1.400	2.324	0	14.412	64.787	.080	.115
4 ORG 08	.800	2.700	170.000	240.000	114.000	2100.000	340.000
5 ORG 08	-.000000	0	.000000	.002381	0	.000476	0
6 ORG 08	0	.850	0	0	10.269	0	59.479
7 ORG 08	320.000						
8 ORG 08	0						
9 ORG 08	19.437						
0 ORG 09						.64095	.64095
1 ORG 09	4.400	7.400	3.500	124.000	1.000	0	.052
2 ORG 09	0	.039683	0	0	0	0	0
3 ORG 09	1.114	0	0	4.286	150.057	.180	.574
4 ORG 09	.800	2.200	180.000	200.000	120.000	2200.000	410.000
5 ORG 09	.000000	0	0	.001746	.008333	0	0
6 ORG 09	0	.557	10.286	0	0	414.260	95.[illegible]
7 ORG 09	310.000						
8 ORG 09	0						
9 ORG 09	37.857						
0 ORG 10						.59264	.59264
1 ORG 10	4.300	6.800	2.700	110.000	.853	0	.000
2 ORG 10	0	.038095	-.000000	0	0	0	0
3 ORG 10	.729	0	0	6.571	114.861	.136	.457
4 ORG 10	.800	2.000	150.000	200.000	125.000	2240.000	420.000
5 ORG 10	-.000000	0	0	.001676	.008000	0	0
6 ORG 10	0	.514	30.571	0	0	331.200	72.457
7 ORG 10	330.000						
8 ORG 10	0						
9 ORG 10	33.257						
0 ORG 11						.65909	.90055
1 ORG 11	4.700	7.400	3.500	122.000	.909	0	1.000
2 ORG 11	0	0	0	0	0	0	0
3 ORG 11	.500	1.359	0	27.529	101.350	.131	.246
4 ORG 11	.900	2.100	200.000	290.000	100.000	2200.000	400.000
5 ORG 11	.000000	-.000000	0	.002273	0	.000455	0
6 ORG 11	0	0	0	0	23.620	0	47.775
7 ORG 11	300.000						
8 ORG 11	0						
9 ORG 11	47.508						
0 ORG 12						1.00000	1.00000
1 ORG 12	3.000	4.000	1.300	70.000	100.000	.125	.000
2 ORG 12	.000010	.000010	.000010	.000001	.009994	.000100	.000010
3 ORG 12	0	0	0	0	0	0	0
4 ORG 12	3.000	1.500	100.000	120.000	40.000	500.000	80.000
5 ORG 12	.000000	.000010	.000001	.000001	.000001	.000000	.000001
6 ORG 12	0	0	0	0	0	0	0
7 ORG 12	80.000						

8 ORG 12	.012498						
9 ORG 12	0						
0 ORG 13						.77934	.77934
1 ORG 13	1.200	3.900	1.200	32.000	50.000	0	.700
2 ORG 13	.000010	.199594	.000010	.000001	.000010	.000100	.000010
3 ORG 13	1.725	0	1.417	36.250	47.500	.112	.050
4 ORG 13	2.700	1.300	90.000	90.000	60.000	900.000	160.000
5 ORG 13	.000060	.000010	.000001	.200001	.000001	.400000	.000041
6 ORG 13	0	.163	7.500	7.500	7.000	214.500	62.[illegible]
7 ORG 13	100.000						
8 ORG 13	.009997						
9 ORG 13	0						
0 ORG 14						.99966	.99966
1 ORG 14	1.800	2.400	1.100	50.000	33.330	.111	.600
2 ORG 14	.000010	.000010	.000010	.000001	.000010	.000100	.000010
3 ORG 14	1.200	1.600	1.400	20.000	66.670	.014	.200
4 ORG 14	2.800	1.500	52.000	95.000	40.000	800.000	170.000
5 ORG 14	.000060	.665531	.000001	.000001	.024991	.000000	.000041
6 ORG 14	0	0	48.000	5.000	0	300.000	90.000
7 ORG 14	110.000						
8 ORG 14	.000001						
9 ORG 14	30.000						
0 ORG 15						.95138	.95138
1 ORG 15	1.600	2.000	1.000	37.000	25.000	0	.000
2 ORG 15	.000010	.000010	.000010	.000001	.000010	.000100	1.168371
3 ORG 15	1.400	2.000	.900	35.000	75.000	.115	0
4 ORG 15	2.900	1.300	60.000	100.000	42.000	700.020	160.000
5 ORG 15	.000060	.000010	.000001	.000001	.023661	.000000	.000241
6 ORG 15	0	.200	40.000	0	0	166.667	72.381
7 ORG 15	120.000						
8 ORG 15	.000001						
9 ORG 15	34.286						
0 ORG 16						.10667	.96612
1 ORG 16	2.000	3.800	.900	40.000	20.000	.125	.700
2 ORG 16	0	0	0	0	.005333	0	0
3 ORG 16	1.400	3.000	5.440	26.000	0	.100	.540
4 ORG 16	3.000	1.000	90.000	95.000	44.000	600.000	150.000
5 ORG 16	0	0	0	0	0	0	.006667
6 ORG 16	1.600	.700	70.000	75.000	3.307	36.000	0
7 ORG 16	130.000						
8 ORG 16	0						
9 ORG 16	2.133						
0 ORG 17						.96564	.96564
1 ORG 17	2.200	1.500	.800	42.000	16.670	0	.500
2 ORG 17	.000010	.000010	.000010	.000001	.000010	.000100	.000010
3 ORG 17	.700	2.367	.457	25.667	79.997	.111	.273
4 ORG 17	2.900	1.200	80.000	85.000	46.000	500.000	140.000
5 ORG 17	.332828	.000010	.000001	.000001	.000001	.001999	.000041
6 ORG 17	0	.250	16.667	11.667	5.800	0	50.000
7 ORG 17	140.000						
8 ORG 17	.000001						
9 ORG 17	58.000						
0 ORG 18						.96801	.96801
1 ORG 18	2.400	2.500	1.300	29.000	14.286	0	.800
2 ORG 18	.000010	.000010	.000010	.000001	.000010	.000100	1.134290
3 ORG 18	.600	1.500	3.000	41.000	85.714	.115	0
4 ORG 18	2.500	1.100	92.000	90.000	46.000	550.000	130.000
5 ORG 18	.000060	.000010	.000001	.000001	.000001	.001616	.000041
6 ORG 18	0	.400	8.000	10.000	3.636	0	38.[illegible]
7 ORG 18	150.000						
8 ORG 18	.000001						
9 ORG 18	56.364						

0 ORG 19						.74491	.74491
1 ORG 19	2.000	2.500	1.200	30.000	12.500	0	[illegible]
2 ORG 19	.000010	.000010	.000010	.000001	.000010	.000100	.000010
3 ORG 19	.400	1.200	3.700	44.000	87.500	.115	[illegible]
4 ORG 19	2.400	1.500	70.000	85.000	50.000	650.000	120.000
5 ORG 19	.000060	.532254	.000001	.000001	.019993	.000000	.000001
6 ORG 19	0	0	30.000	15.000	0	20.000	10.000
7 ORG 19	160.000						
8 ORG 19	.000001						
9 ORG 19	48.000						
0 ORG20						.71702	.71702
1 ORG20	2.800	2.900	1.100	45.000	14.286	0	.700
2 ORG20	.000010	.000010	.000010	.000001	.000010	.000100	.000010
3 ORG20	0	.833	1.313	20.333	79.047	.107	.047
4 ORG20	2.600	1.400	80.000	80.000	52.000	750.000	110.000
5 ORG20	.000060	.511743	.000001	.000001	.019224	.000000	.000001
6 ORG20	0	0	13.333	13.333	0	71.795	4.500
7 ORG20	170.000						
8 ORG20	.000001						
9 ORG20	47.385						
0 ORG 21						.79896	.79896
1 ORG 21	3.000	3.000	1.000	70.000	10.000	.100	.000
2 ORG 21	.000010	.000010	.000010	.011407	.000010	.000100	.000010
3 ORG 21	0	1.000	4.500	0	90.000	.025	0
4 ORG 21	2.300	1.100	60.000	90.000	54.000	850.000	100.000
5 ORG 21	.000060	.000010	.000001	.000001	.000001	.000000	.009998
6 ORG 21	0	.400	40.000	10.000	3.200	180.000	0
7 ORG 21	110.000						
8 ORG 21	.000001						
9 ORG 21	8.000						
0 ORG 22						.88870	.88870
1 ORG 22	2.800	1.800	.700	55.000	100.000	.111	.400
2 ORG 22	.000010	.000010	.000010	.000001	.008883	.000100	.000010
3 ORG 22	.200	2.200	4.200	15.000	0	.414	[illegible]
4 ORG 22	2.400	1.200	70.000	75.000	56.000	900.000	90.000
5 ORG 22	.000060	.000010	.000001	.000001	.000001	.000000	.011101
6 ORG 22	0	.300	30.000	25.000	9.778	300.000	0
7 ORG 22	100.000						
8 ORG 22	.000001						
9 ORG 22	8.889						
0 ORG 23						0	.51027
1 ORG 23	1.200	1.500	.800	27.000	10.000	0	.300
2 ORG 23	0	0	0	0	0	3.200000	0
3 ORG 23	.960	1.180	13.056	21.400	2.000	0	.236
4 ORG 23	2.300	1.000	52.000	75.000	60.000	900.000	200.000
5 ORG 23	0	0	0	0	0	0	.005000
6 ORG 23	0	.880	44.000	67.000	1.280	11.200	0
7 ORG 23	180.000						
8 ORG 23	0						
9 ORG 23	.640						
0 ORG 24						1.00000	1.00000
1 ORG 24	5.600	7.800	2.000	128.000	5.000	0	1.200
2 ORG 24	.057709	.000010	.000010	.000001	.000010	.000100	.000010
3 ORG 24	0	0	0	0	0	0	0
4 ORG 24	3.000	2.800	232.000	300.000	100.000	1500.000	300.000
5 ORG 24	.000060	.000010	.000001	.002254	.009993	.000000	.000001
6 ORG 24	0	0	0	0	0	0	0
7 ORG 24	250.000						
8 ORG 24	.000001						
9 ORG 24	0						
0 ORG 25						.52500	.79137
1 ORG 25	5.200	7.700	2.600	126.000	2.500	0	1.100

2 ORG 25	0	0	0	0	-.000000	0	0
3 ORG 25	.553	1.224	0	19.797	0	[illegible]	[illegible]
4 ORG 25	2.700	2.700	220.000	250.000	115.000	[illegible]	[illegible]
5 ORG 25	.000000	0	0	.002500	0	.000500	0
6 ORG 25	0	.376	27.051	0	11.345	0	12.034
7 ORG 25	330.000						
8 ORG 25	0						
9 ORG 25	2.140						
0 ORG 26						.59427	.75244
1 ORG 26	5.000	6.000	2.400	122.000	3.333	0	1.100
2 ORG 26	0	0	0	0	0	0	0
3 ORG 26	2.300	2.759	0	62.529	153.774	.193	.760
4 ORG 26	2.800	2.500	150.000	240.000	117.000	1600.000	390.000
5 ORG 26	-.000000	0	.002514	.000905	.008547	0	0
6 ORG 26	0	1.150	0	0	0	249.170	39.047
7 ORG 26	260.000						
8 ORG 26	0						
9 ORG 26	50.725						
0 ORG 27						.69733	.93154
1 ORG 27	4.800	7.500	2.700	119.000	1.428	0	.950
2 ORG 27	0	0	.000000	0	0	0	0
3 ORG 27	2.400	3.712	0	67.706	242.010	.304	.828
4 ORG 27	2.900	2.400	160.000	280.000	110.000	1500.000	400.000
5 ORG 27	-.000000	0	.002074	.000963	.009091	0	0
6 ORG 27	0	1.200	0	0	0	354.011	50.452
7 ORG 27	250.000						
8 ORG 27	0						
9 ORG 27	67.316						
0 ORG 28						.82038	.80095
1 ORG 28	4.600	7.000	1.900	112.000	1.067	0	1.000
2 ORG 28	.052521	0	-.000000	0	0	0	0
3 ORG 28	0	1.065	0	7.882	67.402	.080	.127
4 ORG 28	3.000	2.000	210.000	290.000	112.000	1700.000	370.000
5 ORG 28	-.000000	0	0	.001996	.008929	0	0
6 ORG 28	0	.500	2.000	0	0	55.357	.313
7 ORG 28	270.000						
8 ORG 28	0						
9 ORG 28	22.557						
0 ORG 29						.76336	.07834
1 ORG 29	4.700	7.700	2.500	127.000	1.428	0	.900
2 ORG 29	0	0	0	0	0	0	0
3 ORG 29	.268	1.343	0	27.168	97.764	.125	.112
4 ORG 29	2.900	2.300	230.000	300.000	122.000	1800.000	420.000
5 ORG 29	.000000	0	0	.002545	.003017	0	.001272
6 ORG 29	0	.084	21.359	0	0	125.954	0
7 ORG 29	280.000						
8 ORG 29	0						
9 ORG 29	39.695						
0 ORG 30						.57895	.66394
1 ORG 30	4.900	7.800	2.700	128.000	1.053	0	.900
2 ORG 30	0	0	.000000	0	0	0	0
3 ORG 30	1.056	2.404	0	40.463	20.158	.031	.113
4 ORG 30	2.500	2.000	210.000	220.000	124.000	1900.000	320.000
5 ORG 30	0	0	0	.002632	.000000	.000526	0
6 ORG 30	0	.078	45.116	0	0	0	39.308
7 ORG 30	280.000						
8 ORG 30	0						
9 ORG 30	22.000						
0 ORG 31						.57143	.75732
1 ORG 31	5.100	7.600	2.600	124.000	1.000	0	.600
2 ORG 31	0	0	.000000	0	0	0	0
3 ORG 31	1.400	2.324	0	40.412	64.676	.080	.115

4 ORG 31	2.600	2.700	170.000	240.000	114.000	2100.000	340.000
5 ORG 31	-.300000	0	.000000	.002381	0	.000476	0
6 ORG 31	0	.850	0	0	10.269	0	59.479
7 ORG 31	320.000						
8 ORG 31	0						
9 ORG 31	19.437						
0 ORG 32						.44043	.59205
1 ORG 32	4.300	6.800	1.700	110.000	.033	0	.600
2 ORG 32	0	0	-.000000	0	0	0	0
3 ORG 32	.800	1.888	0	30.294	17.745	.028	.042
4 ORG 32	2.500	2.000	150.000	200.000	125.000	2240.000	420.000
5 ORG 32	0	0	.000000	.002232	0	.000446	0
6 ORG 32	0	.250	0	0	9.491	0	10.018
7 ORG 32	330.000						
8 ORG 32	0						
9 ORG 32	20.032						

Appendix H: Sample Organizational Reports

This appendix contains a sample of the organizational reports that may be obtained from the computerized model. The first organizational report presented tells the manager what changes in outputs would be necessary for that organization to achieve maximum effeciency with no change in inputs. The outputs evaluated are listed along the far left hand side of the report. Next to the outputs is the column titled "Observed Values". This column gives the current output values for that organization. The next column to the right, titled "Efficient Output Levels," shows the output values that would have to be achieved by the organization for it to be 100 percent efficient. The column on the far right gives the weighting of the output to the overall efficiency. An organization desiring to improve its efficiency should concentrate on those outputs with the highest weighting. At the bottom of the outputs report, the inputs are listed in the same format except that the second column is titled "No I put Changes Required." This portion of the outputs report tells the manager the relative importance the model attached to each input.

Following the output report is the inputs report. This report shows the managers what changes in inputs would be necessary to achieve maximum efficiency with no corresponding reduction in outputs. The format is identical to the previous report except inputs and outputs are switched. Under the "outputs" heading the column is titled "No Output Changes Required" while the inputs show the values necessary to achieve 100 percent efficiency.

BASE CIVIL ENGR DESIGN SECTION PROD
DECISION MAKING UNIT 3 ORG 03

```
**********************
* SUMMARY OF RESULTS *
**********************
```

EFFICIENCY RANGE = 59.4 TO 75.2 PERCENT
MULTIPLIER FOR EFFICIENT OUTPUT LEVELS = 1.683

```
***********
* OUTPUTS *
***********
```

	OBSERVED VALUES	EFFICIENT OUTPUT LEVELS	PERCENT CONTRIBUTION TO EFFICIENCY
OUTPUT 01	5.0	10.7	0
OUTPUT 02	6.8	14.2	0
OUTPUT 03	3.4	5.7	.0
OUTPUT 05	122.0	267.8	0
OUTPUT 08	3.3	159.4	0
OUTPUT 09	0	.2	0
OUTPUT 10	1.1	2.6	0
OUTPUT 11	1.0	1.7	.0
OUTPUT 13	2.5	5.4	0
OUTPUT14	150.0	252.4	37.7
OUTPUT 15	240.0	403.9	21.7
		TOTAL :	59.4 PERCENT

****
* INPUTS *
****

	OBSERVED VALUES	NO INPUT CHANGES REQUIRED	RELATIVE IMPORTANCE OF INPUTS
INPUT 01	117.0		100.0
INPUT 02	1600.0		0
INPUT 03	390.0		0
INPUT 04	260.0		0
		TOTAL :	100.0 PERCENT

BASE CIVIL ENGR DESIGN SECTION PROD
DECISION MAKING UNIT 3 ORG 03

****
* SUMMARY OF RESULTS *
****

EFFICIENCY RANGE = 59.4 TO 75.2 PERCENT
MULTIPLIER FOR EFFICIENT INPUT LEVELS = .594

****
* OUTPUTS *
****

	OBSERVED VALUES	NO OUTPUT CHANGES REQUIRED	PERCENT CONTRIBUTION TO EFFICIENCY
OUTPUT 01	5.0		0
OUTPUT 02	6.8		0
OUTPUT 03	3.4		.0
OUTPUT 05	122.0		0
OUTPUT 08	3.3		0
OUTPUT 09	0		0
OUTPUT 10	1.1		0
OUTPUT 11	1.0		.0
OUTPUT 13	2.5		0
OUTPUT14	150.0		37.7
OUTPUT 15	240.0		21.7
		TOTAL :	59.4 PERCENT

****
* INPUTS *
****

	OBSERVED VALUES	EFFICIENT INPUT LEVELS	RELATIVE IMPORTANCE OF INPUTS
INPUT 01	117.0	69.5	100.0
INPUT 02	1600.0	701.7	0
INPUT 03	390.0	192.1	0
INPUT 04	260.0	103.8	0
		TOTAL :	100.0 PERCENT

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Captain Christopher D. Ruff was born on 24 December 1957 in Greeley, Colorado. He graduated from high school in Ault, Colorado, in 1976 and attended the United States Air Force Academy from which he received a Bachelor of Science in Civil Engineering in May 1980. Upon graduation, he was assigned to the Ballistic Missile Office at Norton AFB as a Civil Engineering Project Manager. He served there until entering the School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB OH in June 1983.

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